ELEMENTARY LESSONS

IN

ELECTRICITY & MAGNETISM

BY

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ELECTRICITY & MAGNETISM

Part First

CHAPTER I

FRICTIONAL ELECTRICITY

LESSON I. — *Electric Attraction and Repulsion*

1. Electricity. — *Electricity* is the name given to an invisible agent known to us only by the effects which it produces and by various manifestations called *electrical.* These manifestations, at first obscure and even mysterious, are now well understood; though little is yet known of the precise nature of electricity itself. It is neither matter nor energy; yet it apparently can be associated or combined with matter; and energy can be spent in moving it. Indeed its great importance to mankind arises from the circumstance that by its means energy spent in generating electric forces in one part of a system can be made to reappear as electric heat or light or work at some other part of the system; such transfer of energy taking place even to very great distances at an enormous speed. Electricity is apparently as indestructible as

matter or as energy. It can neither be created nor destroyed, but it can be transformed in its relations to matter and to energy, and it can be moved from one place to another. In many ways its behaviour resembles that of an incompressible liquid; in other ways that of a highly attenuated and weightless gas. It appears to exist distributed nearly uniformly throughout all space. Many persons (including the author) are disposed to consider it as identical with the luminiferous ether. If it be not the same thing, there is an intimate relation between the two. That this must be so, is a necessary result of the great discovery of Maxwell — the greatest scientific discovery of the nineteenth century — that light itself is an electric phenomenon, and that the light-waves are merely electric, or, as he put it, electromagnetic waves.

The name *electricity* is also given to that branch of science which deals with electric phenomena and theories. The phenomena, and the science which deals with them, fall under four heads. The manifestations of electricity when standing still are different from those of electricity moving or flowing along: hence we have to consider separately the properties of (i.) statical *charges*, and those of (ii.) *currents*. Further, electricity whirling round or in circulation possesses properties which were independently discovered under the name of (iii.) *magnetism*. Lastly, electricity when in a state of rapid vibration manifests new properties not possessed in any of the previous states, and causes the propagation of (iv.) *waves*. These four branches of the science of electricity are, however, closely connected. The object of the present work is to give the reader a general view of the main facts and their simple relations to one another.

In these first lessons we begin with charges of electricity, their production by friction, by influence, and by various other means, and shall study them mainly by the manifestations of attraction and repulsion to which they give rise. After that we go on to magnetism and

currents, and the relations between them. The subject of electric waves is briefly discussed at the end of the book.

2. Electric Attraction.—If you take a piece of sealing-wax, or of resin, or a glass rod, and rub it upon a piece of flannel or silk, it will be found to have acquired a property which it did not previously possess: namely, the power of attracting to itself such light bodies as chaff, or dust, or bits of paper (Fig. 1). This curious power

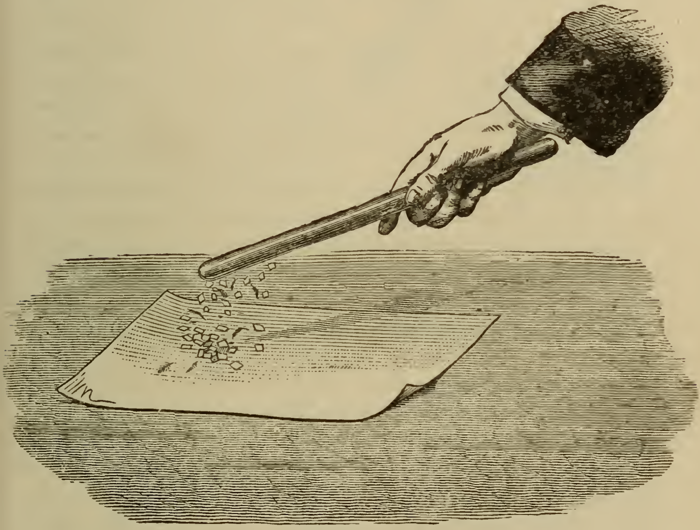

Fig. 1.

was originally discovered to be a property of **amber**, or, as the Greeks called it, ἤλεκτρον, which is mentioned by Thales of Miletus (B.C. 600), and by Theophrastus in his treatise on Gems, as attracting light bodies when rubbed. Although an enormous number of substances possess this property, amber and jet were the only two in which its existence had been recognized by the ancients, or even down to so late a date as the time of Queen Elizabeth.

About the year 1600, Dr. Gilbert of Colchester discovered by experiment that not only amber and jet, but a very large number of substances, such as diamond, sapphire, rock-crystal, glass, sulphur, sealing-wax, resin, etc., which he styled *electrics*,* possess the same property. Ever since his time the name **electricity** † has been employed to denote the agency at work in producing these phenomena. Gilbert also remarked that these experiments are spoiled by the presence of moisture.

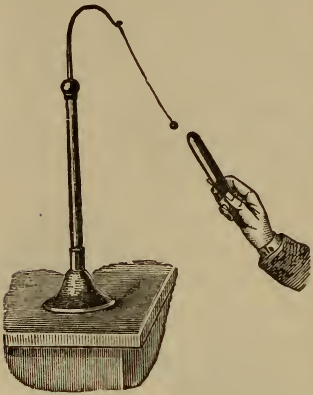

Fig. 2.

3. Further Experiments. — A better way of observing the attracting force is to employ a small ball of elder pith, or of cork, hung by a fine thread from a support, as shown in Fig. 2. A dry warm glass tube, excited by rubbing it briskly with a silk handkerchief, will attract the pith-ball strongly, showing that it is highly electrified. The most suitable rubber, if a stick of sealing-wax is used, will be found to be flannel, woollen cloth, or, best of all, fur. Boyle discovered

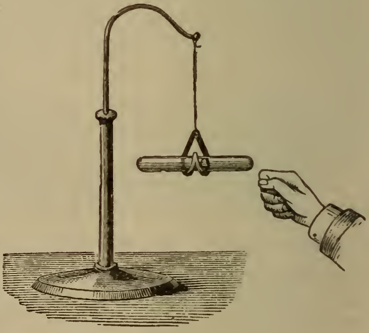

Fig. 3.

* "*Electrica;* quæ attrahunt eadem ratione ut electrum" (Gilbert).

† The first work in which this term was used is that of Robert Boyle, *On the Mechanical Production of Electricity*, published at Oxford in 1675.

that an electrified body is itself attracted by one that has not been electrified. This may be verified (see Fig. 3) by rubbing a stick of sealing-wax, or a glass rod, and hanging it in a wire loop at the end of a *silk* thread. If, then, the hand be held out towards the suspended electrified body, the latter will turn round and approach the hand. So, again, a piece of silk ribbon, if rubbed with warm indiarubber, or even if drawn between two pieces of warm flannel, and then hung up by one end, will be found to be attracted by objects presented to it. If held near the wall of the room it will fly to it and stick to it. With proper precautions it can be shown that *both* the rubber and the thing rubbed are in an electrified state, for both will attract light bodies; but to show this, care must be taken not to handle the rubber too much. Thus, if it is desired to show that when a piece of fur is rubbed upon sealing-wax, the fur becomes also electrified, it is better not to take the fur in the hand, but to cement it to the end of a glass rod as a handle. The reason of this precaution will be explained toward the close of this lesson, and more fully in Lesson IV.

A large number of substances, including iron, gold, brass, and all the metals, when held in the hand and rubbed, exhibit no sign of electrification, — that is to say, do not attract light bodies as rubbed amber and rubbed glass do. Gilbert mentions also pearls, marble, agate, and the lodestone, as substances not excited electrically by rubbing them. Such bodies were, on that account, formerly termed *non-electrics;* but the term is erroneous, for if they are mounted on glass handles and then rubbed with silk or fur, they behave as electrics.

4. Electric Repulsion. — When experimenting, as in Fig. 1, with a rubbed glass rod and bits of chopped paper, or straw, or bran, it will be noticed that these little bits are first attracted and fly up towards the excited rod, but that, having touched it, they are speedily repelled

and fly back to the table. To show this repulsion better, let a small piece of feather or down be hung by a silk thread to a support, and let an electrified glass rod be held near it. It will dart towards the rod and stick to it, and a moment later will dart away from it, repelled by an invisible force (Fig. 4), nor will it again dart towards the rod. If the experiment be repeated with another feather and a stick of sealing-wax rubbed on flannel the same effects will occur. But, if now the hand be held towards the feather, it will rush toward the hand, as the rubbed body (in Fig. 3) did. This proves that the feather, though it has not itself been rubbed, possesses the property originally imparted to the rod by rubbing it. In fact, it has become electrified, by having touched an electrified body which has given part of its electricity to it. It would appear then that two bodies electrified with the same electrification repel one another. This may be confirmed by a further experiment. A rubbed glass rod, hung up as in Fig 3, is repelled by a

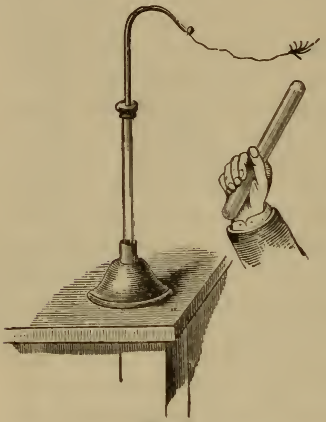

Fig. 4.

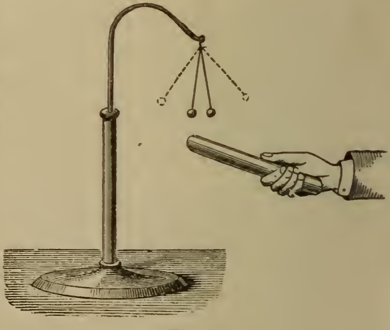

Fig. 5.

similar rubbed glass rod; while a rubbed stick of sealing-wax is repelled by a second rubbed stick of sealing-wax. Another way of showing the repulsion between two similarly electrified bodies is to hang a couple of small pith-balls, by thin linen threads to a glass support, as in Fig. 5, and then touch them both with a rubbed glass rod. They repel one another and fly apart, instead of hanging down side by side, while the near presence of the glass rod will make them open out still wider, for now it repels them both. The self-repulsion of the parts of an electrified body is beautifully illustrated by the experiment of electrifying a soap-bubble, which *expands* when electrified.

5. **Two Kinds of Electrification.**—Electrified bodies do not, however, always repel one another. The feather which (see Fig. 4) has been touched by a rubbed glass rod, and which in consequence is repelled from the rubbed glass, will be *attracted* if a stick of rubbed sealing-wax be presented to it; and conversely, if the feather has been first electrified by touching it with the rubbed sealing-wax, it will be attracted to a rubbed glass rod, though repelled by the rubbed wax. So, again, a rubbed glass rod suspended as in Fig. 3 will be attracted by a rubbed piece of sealing-wax, or resin, or amber, though repelled by a rubbed piece of glass. The two pith-balls touched (as in Fig. 5) with a rubbed glass rod fly from one another by repulsion, and, as we have seen, fly wider asunder when the excited glass rod is held near them; yet they fall nearer together when a rubbed piece of sealing-wax is held under them, being attracted by it. Symmer first observed such phenomena as these, and they were independently discovered by Du Fay, who suggested in explanation of them that there were two different kinds of electricity which attracted one another while each repelled itself. The electricity produced on glass by rubbing it with silk he called *vitreous* electricity, supposing, though erroneously, that glass could yield no

other kind; and the electricity excited in such substances as sealing-wax, resin, shellac, indiarubber, and amber, by rubbing them on wool or flannel, he termed *resinous* electricity. The kind of electricity produced is, however, found to depend not only on the thing rubbed but on the rubber also; for glass yields "resinous" electricity when rubbed with a cat's skin, and resin yields "vitreous" electricity if rubbed with a soft amalgam of tin and mercury spread on leather. Hence these names have been abandoned in favour of the more appropriate terms introduced by Franklin, who called the electricity excited upon glass by rubbing it with silk *positive* electricity, and that produced on resinous bodies by friction with wool or fur, *negative* electricity. The observations of Symmer and Du Fay may therefore be stated as follows:—Two positively electrified bodies apparently repel one another: two negatively electrified bodies apparently repel one another: but a positively electrified body and a negatively electrified body apparently attract one another. It is now known that these effects which appear like a repulsion and an attraction between bodies at a distance from one another are really due to actions going on *in the medium* between them. The positive charge does not really attract the negative charge that is near it; but both are urged toward one another by stresses in the medium in the intervening space.

6. Simultaneous Production of both Electrical States.—Neither kind of electrification is produced alone; there is always an equal quantity of both kinds produced; one kind appearing on the thing rubbed and an equal amount of the other kind on the rubber. The clearest proof that these amounts are *equal* can be given in some cases. For it is found that if both the − electricity of the rubber and the + electricity of the thing rubbed be imparted to a third body, that third body will show *no electrification at all*, the two equal and opposite electrifications having exactly neutralized each other. A simple

experiment consists in rubbing together a disk of sealing-wax and one covered with flannel, both being held by insulating handles. To test them is required an insulated pot and an electroscope, as in Fig. 29. If either disk be inserted in the pot the leaves of the electroscope will diverge; but if both are inserted at the same time the leaves do not diverge, showing that the two charges on the disks are equal and of opposite sign.

In the following list the bodies are arranged in such an order that if any two be rubbed together the one which stands earlier in the series becomes positively electrified, and the one that stands later negatively electrified:— *Fur*, *wool*, *ivory*, *glass*, *silk*, *metals*, *sulphur*, *indiarubber*, *guttapercha*, *collodion*, or *celluloid*.

7. Theories of Electricity. — Several theories have been advanced to account for these phenomena, but all are more or less unsatisfactory. Symmer proposed a "**two-fluid**" **theory**, according to which there are two imponderable electric fluids of opposite kinds, which neutralize one another when they combine, and which exist combined in equal quantities in all bodies until their condition is disturbed by friction. A modification of this theory was made by Franklin, who proposed instead a "**one-fluid**" **theory**, according to which there is a single electric fluid distributed usually uniformly in all bodies, but which, when they are subjected to friction, distributes itself unequally between the rubber and the thing rubbed, one having more of the fluid, the other less, than the average. Hence the terms *positive* and *negative*, which are still retained; that body which is supposed to have an excess being said to be charged with positive electricity (usually denoted by the *plus* sign +), while that which is supposed to have less is said to be charged with negative electricity (and is denoted by the *minus* sign −). These terms are, however, purely arbitrary, for in the present state of science we do not know which of these two states really means more and

which means less. In many ways electricity behaves as a weightless substance as incompressible as any material liquid. It is, however, quite certain that *electricity is not a material fluid*, whatever else it may be. For while it resembles a fluid in its property of apparently flowing from one point to another, it differs from every known fluid in almost every other respect. It possesses no weight; it repels itself. It is, moreover, quite impossible to conceive of two fluids whose properties should in every respect be the precise opposites of one another. For these reasons it is clearly misleading to speak of an electric fluid or fluids, however convenient the term may seem to be. In metals and other good conductors electricity can apparently move and flow quite easily in *currents*. In transparent solids, such as glass and resin, and in many transparent liquids such as oils, and in gases such as the air (if still, and not rarefied) electricity apparently cannot flow. Even a vacuum appears to be a non-conductor. In the case of all non-conductors electricity can only be moved by an action known as *displacement* (see Art. 57).

It appears then that in metals electricity can easily pass from molecule to molecule; but in the case of non-conductors the electricity is in some way stuck to the molecules, or associated with them. Some electricians, notably Faraday, have propounded a **molecular theory** of electricity, according to which the electrical states are the result of certain peculiar conditions of the molecules of the surfaces that have been rubbed. Another view is to regard the state of electrification as related to the *ether* (the highly-attenuated medium which fills all space, and is the vehicle by which light is transmitted), which is known to be associated with the molecules of matter. Some indeed hold that the ether itself is electricity; and that the two states of positive and negative electrification are simply due to displacement of the ether at the surfaces of bodies. In these lessons we shall avoid as

far as possible all theories, and shall be content to use the term electricity.

8. **Charge.** — The quantity of electrification of either kind produced by friction or other means upon the surface of a body is spoken of as a **charge**, and a body when electrified is said to be *charged*. It is clear that there may be charges of different values as well as of either kind. When the charge of electricity is removed from a charged body it is said to be *discharged*. Good conductors of electricity are instantaneously discharged if touched by the hand or by any conductor in contact with the ground, the charge thus finding a means of escaping to earth or to surrounding walls. A body that is not a good conductor may be readily discharged by passing it rapidly through the flame of a spirit-lamp or a candle; for the hot gases instantly carry off the charge and dissipate it in the air.

Electricity may either reside upon the surface of bodies as a *charge*, or flow through their substance as a *current*. That branch of the science which treats of the laws of the charges, that is to say, of electricity at rest, upon the surface of bodies is termed **electrostatics**, and is dealt with in Chapter IV. The branch of the subject which treats of the flow of electricity in currents is dealt with in Chapter III., and other later portions of this book.

9. **Modes of representing Electrification.** — Several modes are used to represent the electrification of surfaces. In Figs. 6, 7, and 8 are represented two disks — A covered with woollen cloth, B of some resinous body, — which have been rubbed together so that A has become positively, B negatively electrified. In Fig. 6 the surfaces are marked with *plus* (+) and *minus* (−) signs. In Fig. 7 dotted lines are drawn just outside the posi-

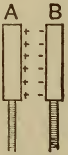

Fig. 6.

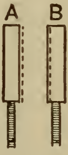

Fig. 7.

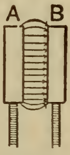

Fig. 8.

tively electrified surface and just within the negatively electrified surface, as though one had a surplus and the other a deficit of electricity. In Fig. 8 lines are drawn across the intervening space from the positively electrified surface to the opposite negative charge. The advantages of this last mode are explained in Art. 13.

10. Conductors and Insulators. — The term "conductors," used above, is applied to those bodies which readily allow electricity to flow through them. Roughly speaking, bodies may be divided into two classes — those which conduct and those which do not; though very many substances are partial conductors, and cannot well be classed in either category. All the metals conduct well; the human body conducts, and so does water. On the other hand glass, sealing-wax, silk, shellac, gutta-percha, indiarubber, resin, fatty substances generally, and the air, are **non-conductors**. On this account these substances are used to make supports and handles for electrical apparatus where it is important that the electricity should not leak away; hence they are sometimes called **insulators** or *isolators*. Faraday termed them **dielectrics**. We have remarked above that the name of *non-electrics* was given to those substances which, like the metals, yield no sign of electrification when held in the hand and rubbed. We now know the reason why they show no electrification; for, being good conductors, the electrification flows away as fast as it is generated. The observation of Gilbert that electrical experiments fail in damp weather is also explained by the knowledge that water is a conductor, the film of moisture on the surface of damp bodies causing the electricity produced by friction to leak away as fast as it is generated.

11. Other Electrical Effects. — The production of electricity by friction is attested by other effects than those of attraction and repulsion, which hitherto we have assumed to be the test of the presence of electricity. Otto von Guericke first observed that sparks and flashes

of light could be obtained from highly electrified bodies at the moment when they were discharged. Such sparks are usually accompanied by a snapping sound, suggesting on a small scale the thunder accompanying the lightning spark, as was remarked by Newton and other early observers. Pale flashes of light are also produced by the discharge of electricity through tubes partially exhausted of air by the air-pump. Other effects will be noticed in due course.

12. Other Sources of Electrification. — The student must be reminded that *friction* is by no means the only source of electrification. The other sources, percussion, compression, heat, chemical action, physiological action, contact of metals, etc., will be treated of in Lesson VII. We will simply remark here that friction between two different substances *always* produces electrical separation, no matter what the substances may be. Symmer observed the production of electrification when a silk stocking was drawn over a woollen one, though woollen rubbed upon woollen, or silk rubbed upon silk, produces no electrical effect. If, however, a piece of rough glass be rubbed on a piece of smooth glass, electrification is observed; and indeed the conditions of the surface play a very important part in the production of electrification by friction. In general, of two bodies thus rubbed together, that one becomes negatively electrical whose particles are the more easily removed by friction. Differences of temperature also affect the electrical conditions of bodies, a warm body being usually negative when rubbed on a cold piece of the same substance. The quantity of electrification produced is, however, not proportional to the amount of the actual mechanical friction; hence it appears doubtful whether friction is truly the cause of the electrification. Something certainly happens when the surfaces of two different substances are brought into intimate contact, which has the result that when they are drawn apart they are found (provided at least

one of them is a non-conductor) to have acquired opposite charges of electrification; one surface having apparently taken some electricity from the other. But these opposite charges attract one another and cannot be drawn apart without there being mechanical work done upon the system. The work thus spent is stored up in the act of separating the charged surfaces; and as long as the charges remain separated they constitute a store of potential energy. The so-called frictional electric machines are therefore machines for bringing dissimilar substances into intimate contact, and then drawing apart the particles that have touched one another and become electrical.

If the two bodies that are rubbed together are both good conductors, they will not become strongly electrified, even if held on insulating handles. It is quite likely, however, that the heat produced by friction, as in the bearings of machinery, is due to electric currents generated where the surfaces meet and slip.

13. Electric Field. — Whenever two oppositely charged surfaces are placed near one another they tend to move together, and the space between them is found to be thrown into a peculiar state of stress, as though the medium in between had been stretched. To explore the space between two bodies one of which has been positively and the other negatively electrified, we may use a light pointer (Fig. 9) made of a small piece of very thin paper pierced with a hole through which passes a long thread of glass. It will be found that this pointer tends to point across from the positively electrified surface to the negatively electrified surface, along invisible *lines of electric force*. The space so filled with electric lines of force is called an *electric field*. In Fig. 8 A and B represent two bodies the surfaces of which have been electrified, the one positively, the other negatively. In

Fig. 9.

the field between them the electric lines pass across almost straight, except near the edges, where they are curved. Electric lines of force start from a positively charged surface at one end, and end on a negatively charged surface at the other end. They never meet or cross one another. Their direction indicates that of the resultant electric force at every point through which they pass. The stress in the medium thus mapped out by the lines of force acts as a tension along them, as though they tended to shorten themselves. In fact in Fig. 8 the tension in the medium draws the two surfaces together. There is also a pressure in the medium at right angles to the lines, tending to widen the distance between them. Fig. 10 represents a ball which has been positively electrified, and placed at a distance from other objects; the lines in the field being simply radial.

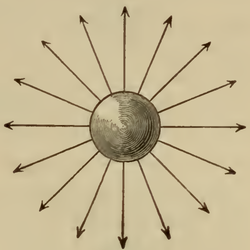

Fig. 10.

Lesson II. — *Electroscopes*

14. Simple Electroscopes. — An instrument for detecting whether a body is electrified or not, and whether the electrification is positive or negative, is termed an **Electroscope.** The feather which was attracted or repelled, and the two pith-balls which flew apart, as we found in Lesson I., are in reality simple electroscopes. There are, however, a number of pieces of apparatus better adapted for this particular purpose, some of which we will describe.

15. Needle Electroscope. — The earliest electroscope was that devised by Dr. Gilbert, and shown in Fig. 11, which consists of a stiff strip balanced lightly upon a sharp point. A thin strip of brass or wood, a straw, or

even a goose quill, balanced upon a sewing needle, will serve equally well. When an electrified body is held near

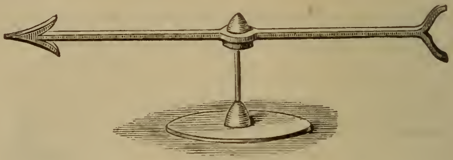

Fig. 11.

the electroscope it is attracted and turned round, and will thus indicate the presence of electric charges far too feeble to attract bits of paper from a table.

16. Gold-Leaf Electroscope. — A still more sensi-

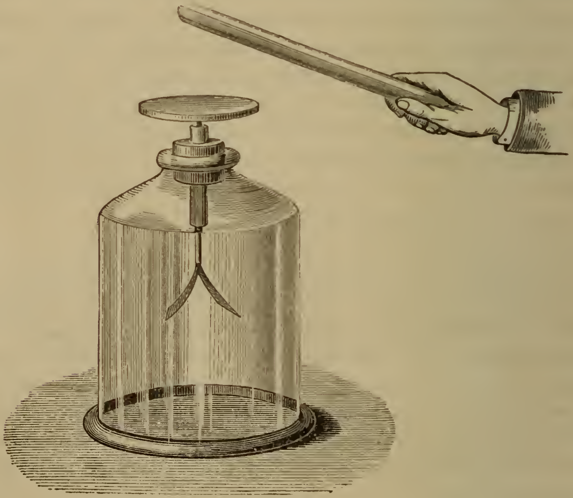

Fig. 12.

tive instrument is the **Gold-Leaf Electroscope**, invented by Bennet, and shown in Fig. 12. We have seen how two pith-balls when similarly electrified repel one

another and stand apart, gravity being partly overcome by the force of the electric repulsion. A couple of narrow strips of the thinnest tissue paper, hung upon a support, will behave similarly when electrified. But the best results are obtained with two strips of gold leaf, which, being excessively thin, is much lighter than the thinnest paper. The Gold-Leaf Electroscope is conveniently made by suspending the two leaves within a wide-mouthed glass jar, which both serves to protect them from draughts of air and to support them from contact with the ground. The mouth of the jar should be closed by a plug of paraffin wax, through which is pushed a bit of varnished glass tube. Through this passes a stiff brass wire, the lower end of which is bent at a right angle to receive the two strips of gold leaf, while the upper supports a flat plate of metal, or may be furnished with a brass knob. When kept dry and free from dust it will indicate excessively small quantities of electrification. A rubbed glass rod, even while two or three feet from the instrument, will cause the leaves to repel one another. The chips produced by sharpening a pencil, falling on the electroscope top, are seen to be electrified. If the knob be even brushed with a small camel's hair brush, the slight friction produces a perceptible effect. With this instrument all kinds of friction can be shown to produce electrification. Let a person, standing upon an insulating support, — such as a stool with glass legs, or a board supported on four glass tumblers, — be briskly struck with a silk handkerchief, or with a fox's tail, or even brushed with a clothes brush, he will be electrified, as will be indicated by the electroscope if he place one hand on the knob at the top of it. The Gold-Leaf Electroscope can further be used to indicate the *kind* of electrification on an excited body. Thus, suppose we rubbed a piece of brown paper with a piece of indiarubber and desired to find out whether the electrification excited on the paper was + or −, we should

proceed as follows:—First charge the gold leaves of the electroscope by touching the knob with a glass rod rubbed on silk. The leaves diverge, being electrified with + electrification. When they are thus charged the approach of a body which is positively electrified will cause them to diverge still more widely; while, on the approach of one negatively electrified, they will tend to close together. If now the brown paper be brought near the electroscope, the leaves will be seen to diverge more, proving the electrification of the paper to be of the same kind as that with which the electroscope is charged, or positive.

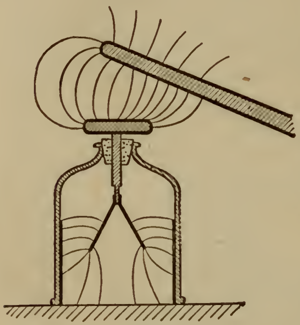

Fig. 13

Sometimes the outer surface of the glass jar containing the gold leaves is covered with wire gauze or strips of foil to shield the leaves from the influence of external bodies. A preferable way is to use glass of a kind that conducts.

The part played by the surrounding medium in the operation of the electroscope is illustrated by Fig. 13. Of the electric lines in the field surrounding the rubbed rod a number will pass into the metal cap of the electroscope and emerge below through the leaves. The nearer the rod is brought, the greater will be the number of electric lines thus affecting the instrument. There being a tension along the lines and a pressure across them, the effect is to draw the gold leaves apart as though they repelled each other.

The Gold-Leaf Electroscope will also indicate roughly the amount of electrification on a body placed in contact with it, for the gold leaves open out more widely when the charge thus imparted to them is greater. For exact measurement, however, of the degree of electrification,

recourse must be had to the instruments known as Electrometers, described in Lesson XXII.

In another form of electroscope (Bohnenberger's) a single gold leaf is used, and is suspended between two metallic plates, one of which can be positively, the other negatively electrified, by placing them in communication with the poles of a "dry pile" (Art. 193). If the gold leaf be charged positively or negatively it will be attracted to one side and repelled from the other, according to the law of attraction and repulsion mentioned in Art. 4.

17. Henley's Semaphore. — As an indicator for large charges of electricity there is sometimes used a semaphore like that shown in Fig. 14. It consists of a pith-ball at the end of a light arm fixed on a pivot to an upright. When the whole is electrified the pith-ball is repelled from the upright and flies out at an angle, indicated on a graduated scale or dial behind it. This little electroscope, which is seldom used except to show whether an electric machine or a Leyden battery is charged, must on no account be confused with the delicate "Quadrant Electrometer" described in Lesson XXII., whose object is to *measure* very small charges of electricity — not to *indicate* large ones.

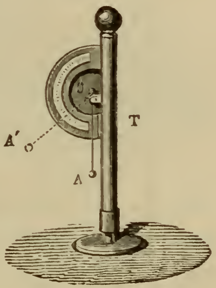

Fig. 14.

18. The Torsion Balance. — Although more properly an *Electrometer* than a mere *Electroscope*, it will be most convenient to describe here the instrument known as the Torsion Balance (Fig. 15). This instrument, once famous, but now quite obsolete, served to measure the force of the repulsion between two similarly electrified bodies, by balancing the repelling force against the force exerted by a fine wire in untwisting itself after it has been twisted. The torsion balance consists of a light arm

or lever of shellac suspended within a cylindrical glass case by means of a fine silver wire. At one end this lever is furnished with a gilt pith-ball *n*. The upper end of the silver wire is fastened to a brass top, upon which a circle, divided into degrees, is cut. This top can be turned round in the tube which supports it, and is called the torsion-head. Through an aperture in the cover there can be introduced a second gilt pith-ball *m*, fixed to the end of a vertical glass rod *a*. Round the glass case, at the level of the pith-balls, a circle is drawn, and divided also into degrees.

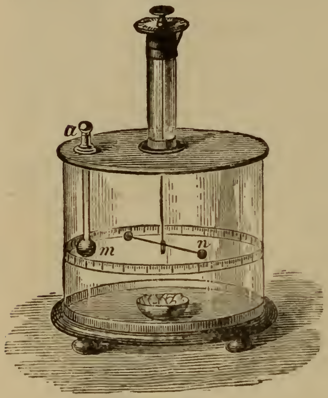

Fig. 15.

In using the torsion balance to measure the amount of a charge of electricity, the following method is adopted:—First, the torsion-head is turned round until the two pith-balls *m* and *n* just touch one another. Then the glass rod *a* is taken out, and the charge of electricity to be measured is imparted to the ball *m*, which is then replaced in the balance. As soon as *m* and *n* touch one another, part of the charge passes from *m* to *n*, and they repel one another because they are then similarly electrified. The ball *n*, therefore, is driven round and twists the wire up to a certain extent. The force of repulsion becomes less and less as *n* gets farther and farther from *m*; but the force of the twist gets greater and greater the more the wire is twisted. Hence these two forces will balance one another when the balls are separated by a certain distance, and it is clear that a large charge of electricity will repel the ball *n* with a greater force than a lesser charge would. The

distance through which the ball is repelled is read off in angular degrees of the scale. When a wire is twisted, the force with which it tends to untwist is precisely proportional to the amount of the twist. The force required to twist the wire ten degrees is just ten times as great as the force required to twist it one degree. In other words, *the* **force** *of torsion is proportional to the* **angle** *of torsion.* The angular distance between the two balls is, when they are not very widely separated, very nearly proportional to the actual straight distance between them, and represents the force exerted between electrified balls *at that distance* apart. The student must, however, carefully distinguish between the measurement of the **force** and the measurement of the actual **quantity** of electricity with which the instrument is charged. For the force exerted between the electrified balls will vary at different distances according to a particular law known as the "law of inverse squares," which requires to be carefully explained.

19. The Law of Inverse Squares. — Coulomb proved, by means of the Torsion Balance, that the force exerted between two small electrified bodies varies inversely as the square of the distance between them when the distance is varied. Thus, suppose two small electrified bodies 1 inch apart repel one another with a certain force, at a distance of 2 inches the force will be found to be only one quarter as great as the force at 1 inch; and at 10 inches it will be only $\frac{1}{100}$ part as great as at 1 inch. This law is proved by the following experiment with the torsion balance. The two scales were adjusted to 0°, and a certain charge was then imparted to the balls. The ball n was repelled round to a distance of 36°. The twist on the wire between its upper and lower ends was also 36°, or the force tending to repel was thirty-six times as great as the force required to twist the wire by 1°. The torsion-head was now turned round so as to twist the thread at the top and force

the ball n nearer to m, and was turned round until the distance between n and m was halved. To bring down this distance from 36° to 18°, it was found needful to twist the torsion-head through 126°. The total twist between the upper and lower ends of the wire was now 126° + 18°, or 144°; and the force was 144 times as great as that force which would twist the wire 1°. But 144 is four times as great as 36; hence we see that while the distance had been reduced to one *half*, the force between the balls had become *four times* as great. Had we reduced the distance to *one quarter*, or 9°, the total torsion would have been found to be 576°, or *sixteen* times as great; proving the force to vary **inversely as the square of the distance.**

In practice it requires great experience and skill to obtain results as exact as this, for there are many sources of inaccuracy in the instrument. The balls must be very small, in proportion to the distances between them. The charges of electricity on the balls are found, moreover, to become gradually less and less, as if the electricity leaked away into the air. This loss is less if the apparatus be quite dry. It is therefore usual to dry the interior by placing inside the case a cup containing either chloride of calcium, or pumice stone soaked with strong sulphuric acid, to absorb the moisture.

Before leaving the subject of electric forces, it may be well to mention that the force of *attraction* between two oppositely electrified bodies varies also inversely as the square of the distance between them. And in every case, whether of attraction or repulsion, the force at any given distance is **proportional to the product of the two quantities** of electricity on the bodies. Thus, if we had separately given a charge of 2 to the ball m and a charge of 3 to the ball n, the force between them will be $3 \times 2 = 6$ times as great as if each had had a charge of 1 given to it. It must be remembered, however, that the

law of inverse squares is only true when applied to the case of bodies so small, as compared with the distance between them, that they are mere points. For flat, large, or elongated bodies the law of inverse squares does not hold good. The attraction between two large flat disks oppositely electrified with given charges, and placed near together, does not vary with the distance.

20. Field between two Balls. — The electric field (Art. 13) between two oppositely electrified balls is found to consist of curved lines. By the principle laid down in Art. 13, there is a tension along these lines so that they tend not only to draw the two balls together, but also to draw the electrifications on the surfaces of the balls toward one another.

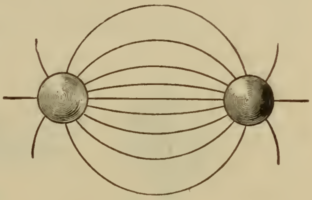

Fig. 16.

There is also a lateral pressure in the medium tending to keep the electric lines apart from one another. One result of these actions is that the charges are no longer equally distributed over the surfaces, but are more dense on the parts that approach most nearly.

21. Unit Quantity of Electricity. — In consequence of these laws of attraction and repulsion, it is found most convenient to adopt the following definition for that quantity of electricity which we take for a **unit** or standard by which to measure other quantities of electricity. *One (electrostatic) Unit of Electricity is that quantity which, when placed at a distance of one centimetre in air from a similar and equal quantity, repels it with a force of one dyne.* If instead of air another medium occupies the space, the force will be different. For example, if petroleum is used the force exerted between given charges will be about half as great (see Art. 56). Further information about the measurement of electrical quantities is given in Lessons XXI. and XXII.

Lesson III. — *Electrification by Influence*

22. Influence. — We have now learned how two charged bodies may apparently attract or repel one another. It is sometimes said that it is the charges in the bodies which attract or repel one another; but as electrification is not known to exist except in or on material bodies, the proof that it is the charges themselves which are acted upon is only indirect. Nevertheless there are certain matters which support this view, one of

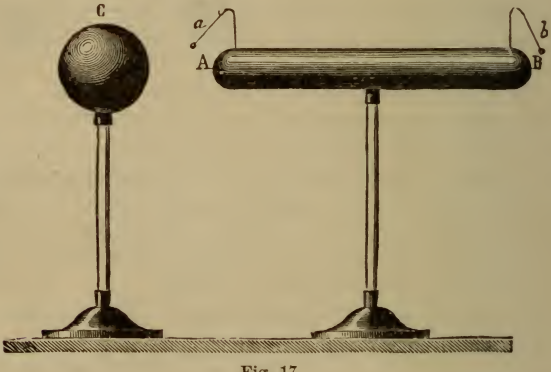

Fig. 17.

these being the electric influence exerted by an electrified body upon one not electrified.

Suppose we electrify positively a ball C, shown in Fig. 17, and hold it near to a body that has not been electrified, what will occur? We take for this experiment the apparatus shown on the right, consisting of a long sausage-shaped piece of metal, either hollow or solid, held upon a glass support. This "conductor," so called because it is made of metal which permits electricity to pass freely through it or over its surface, is supported on glass to

prevent the escape of electricity to the earth, glass being a non-conductor. The influence of the positive charge of the ball placed near this conductor is found to *induce* electrification on the conductor, which, although it has not been rubbed itself, will be found to behave at its two ends as an electrified body. The ends of the conductor will attract little bits of paper; and if pith-balls be hung to the ends they are found to be repelled. It will, however, be found that the middle region of the long-shaped conductor will give no sign of any electrification. Further examination will show that the two electrifications on the ends of the conductor are of opposite kinds, that nearest the excited glass ball being a negative charge, and that at the farthest end being an equal charge, but of positive sign. It appears then that a positive charge attracts negative and repels positive, and that this influence can be exerted at a distance from a body. If we had begun with a charge of negative electrification upon a stick of sealing-wax, the presence of the negative charge near the conductor would have induced a positive charge on the near end, and negative on the far end. This action, discovered in 1753 by John Canton, is spoken of as **influence** or **electrostatic induction.*** It will take place across a considerable distance. Even if a large sheet of glass be placed between, the same effect will be produced. When the electrified body is removed both the charges disappear and leave no trace behind, and the glass ball is found to be just as much electrified as before; it has parted with none of its own charge. It

* The word *induction* originally used was intended to denote an action at a distance, as distinguished from *conduction*, which implied the conveyance of the action by a material conductor. But there were discovered other actions at a distance, namely, the induction of currents by moving magnets, or by other currents, and the induction of magnetism in iron in the presence of a neighbouring magnet. As the term *induction* has now been officially adopted for the induction of currents, its use in other senses ought to be dropped. Hence the preference now given to the term *influence* for the induction of charges by charges.

will be remembered that on one theory a body charged positively is regarded as having *more* electricity than the things round it, while one with a negative charge is regarded as having *less*. According to this view it would appear that when a body (such as the + electrified glass ball) having more electricity than things around it is placed near an insulated conductor, the uniform distribution of electricity in that conductor is disturbed, the electricity flowing away from that end which is near the + body, leaving less than usual at that end, and producing more than usual at the other end. This view of things will account for the disappearance of all signs of electrification when the electrified body is removed, for then the conductor returns to its former condition; and being neither more nor less electrified than all the objects around on the surface of the earth, will show neither positive nor negative charge.

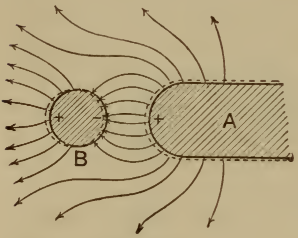

Fig. 18.

The action is not, however, a mere action at a distance; it is one in which the intervening medium takes an essential part. Consider (Fig. 18) what takes place when an insulated, non-electrified metal ball B is brought under the influence of a positively electrified body A. At once some of the electric lines of the field that surrounds A pass through B, entering it at the side nearer A, and leaving it at the farther side. As the ball B has no charge of its own, as many electric lines will enter on one side as leave on the other; or, in other words, the induced negative charge on one side and the induced positive charge on the other will be exactly equal in amount. They will not, however, be quite equally distributed, the negative charge on the side nearer A being more concentrated, and the lines in the field on that side denser.

23. Effects of Influence. — If the conductor be made in two parts, which while under the influence of the electrified body are separated, then on the removal of the electrified body the two charges can no longer return to neutralize one another, but remain each on its own portion of the conductor.

If the conductor be not insulated on glass supports, but placed in contact with the ground, that end only which is nearest the electrified body will be found to be electrified. The repelled charge is indeed repelled as far as possible into the walls of the room; or, if the experiment be performed in the open air, into the earth. One kind of electrification only is under these circumstances to be found, namely, the opposite kind to that of the excited body, whichever this may be. The same effect occurs in this case as if an electrified body had the power of attracting up the opposite kind of charge out of the earth.

The quantity of the two charges thus separated by influence on such a conductor in the presence of a charge of electricity, depends upon the amount of the charge, and upon the distance of the charged body from the conductor. A highly electrified glass rod will exert a greater influence than a less highly electrified one; and it produces a greater effect as it is brought nearer and nearer. The utmost it can do will be to induce on the near end a negative charge equal in amount to its own positive charge, and a similar amount of positive electrification at the far end; but usually, before the electrified body can be brought so near as to do this, something else occurs which entirely alters the condition of things. As the electrified body is brought nearer and nearer, the charges of opposite sign on the two opposed surfaces attract one another more and more strongly and accumulate more and more densely, until, as the electrified body approaches very near, a spark is seen to dart across, the two charges thus rushing together to neutralize one

another, leaving the induced charge of positive electricity, which was formerly repelled to the other end of the conductor, as a permanent charge after the electrified body has been removed.

In Fig. 19 is illustrated the operation of gradually lowering down over a table a positively electrified metal ball. The nearer it approaches the table, the more does the electric field surrounding it concentrate itself in the gap between the ball and the table top; the latter becoming negatively electrified by influence. Where the electric lines are densest the tension in the medium is greatest, until when the ball is lowered still further the mechanical resistance of the air can no longer withstand the stress; it breaks down and the layer of air is pierced by a spark. If oil is used as a surrounding medium instead of air, it will be found to stand a much greater stress without being pierced.

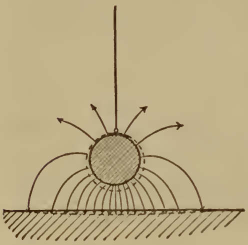
Fig. 19.

24. Attraction due to Influence. — We are now able to apply the principle of influence to explain why an electrified body should attract things that have not been electrified at all. Fig. 18, on p. 26, may be taken to represent a light metal ball B hung from a silk thread presented to the end of a rubbed glass rod A. The positive charge on A produces *by influence* a negative charge on the nearer side of B and an equal positive charge on the far side of B. The nearer half of the ball will therefore be attracted, and the farther half repelled; but the attraction will be stronger than the repulsion, because the attracted charge is nearer than the repelled. Hence on the whole the ball will be attracted. It can easily be observed that if a ball of non-conducting substance, such as wax, be employed, it is not attracted

so much as a ball of conducting material. This in itself *proves* that influence really precedes attraction.

Another way of stating the facts is as follows: — The tension along the electric field on the right of B will be greater than that on the left, because of the greater concentration of the electric lines on the right.

25. Dielectric Power. — We have pointed out several times what part the intervening medium plays in these actions at a distance. The air, oil, glass, or other material between does not act simply as a non-conductor; it takes part in the propagation of the electric forces. Hence Faraday, who discovered this fact, termed such materials *dielectrics*. Had oil, or solid sulphur, or glass been used instead of air, the influence exerted by the presence of the electrified body at the same distance would have been greater. The power of a non-conducting substance to convey the influence of an electrified body across it is called its *dielectric power* (or was formerly called its specific *inductive capacity*, see Art. 56 and Lesson XXIII.).

26. The Electrophorus. — We are now prepared to explain the operation of a simple and ingenious instrument, devised by Volta in 1775, for the purpose of procuring, by the principle of influence, an unlimited number of charges of electricity from one single charge. This instrument* is the **Electrophorus** (Fig. 20). It consists of two parts, a round cake of resinous material cast in a metal dish or "sole," about 12 inches in diameter, and a round disk of slightly smaller diameter made of metal, or of wood covered with tinfoil, and provided with a glass handle. Shellac, or sealing-wax, or a mixture of resin, shellac, and Venice turpentine, may be used to make the cake. A slab of sulphur will also answer, but it is liable to crack. Sheets of hard ebonized indiarubber are excellent; but the surface of this substance

* Volta's electrophorus was announced in 1775. Its principle had already been anticipated by Wilcke, who in 1762 described to the Swedish Academy of Sciences two "charging-machines" working by influence.

requires occasional washing with ammonia and rubbing with paraffin oil, as the sulphur contained in it is liable to oxidize and to attract moisture. To use the electrophorus the resinous cake must be beaten or rubbed with a warm piece of woollen cloth, or, better still, with a cat's

Fig. 20.

skin. The disk or "cover" is then placed upon the cake, touched momentarily with the finger, then removed by taking it up by the glass handle, when it is found to be powerfully electrified with a positive charge, so much so indeed as to yield a spark when the knuckle is presented to it. The "cover" may be replaced, touched, and once more removed, and will thus yield any number of sparks,

the original charge on the resinous plate meanwhile remaining practically as strong as before.

The theory of the electrophorus is very simple, provided the student has clearly grasped the principle of influence explained above. When the resinous cake is first beaten with the cat's skin its surface is negatively electrified, as indicated in Fig. 21. When the metal disk is placed down upon it, it rests really only on three or four points of the surface, and may be regarded as an insulated conductor in the presence of an electrified body. The negative electrification of the cake therefore acts by influence on the metallic disk or "cover," the natural electricity in it being displaced downwards, producing a positive charge on the under side, and leaving the upper

Fig. 21.

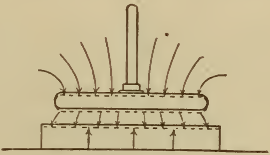

Fig. 22.

side negatively electrified. This state of things is shown in Fig. 22. If now the cover be touched for an instant with the finger, the negative charge of the upper surface will be neutralized by electricity flowing in from the earth through the hand and body of the experimenter. The attracted positive charge will, however, remain, being bound as it were by its attraction towards the negative charge on the cake. Fig. 23 shows the condition of things after the cover has been touched. If, finally, the cover be lifted by its handle, the remaining positive charge will be no longer "bound" on the lower surface by attraction, but will distribute itself on both sides of the cover, and may be used to give a spark, as already said. It is clear that no part of the original charge has been consumed in the process, which may be repeated as

often as desired. As a matter of fact, the charge on the cake slowly dissipates — especially if the air be damp. Hence it is needful sometimes to renew the original charge by afresh beating the cake with the cat's skin. The labour of touching the cover with the finger at each operation may be saved by having a pin of brass or a strip of tinfoil projecting from the metallic "sole" on to the top of the cake, so that it touches the plate each time, and thus neutralizes the negative charge by allowing electricity to flow in from the earth.

The principle of the electrophorus may then be summed up in the following sentence. *A conductor if*

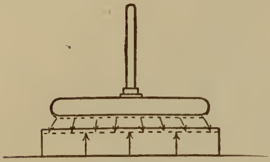

Fig. 23.

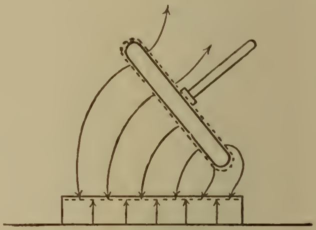

Fig. 24.

*touched while under the influence of a charged body acquires thereby a charge of opposite sign.**

Since the electricity thus yielded by the electrophorus is not obtained at the expense of any part of the original charge, it is a matter of some interest to inquire what the source is from which the energy of this apparently unlimited supply is drawn; for it cannot be called into

* Priestley, in 1767, stated this principle in the following language: — "The electric fluid, when there is a redundancy of it in any body, repels the electric fluid in any other body, when they are brought within the sphere of each other's *influence*, and drives it into the remote parts of the body; or quite out of the body, if there be any outlet for that purpose. In other words, bodies immerged in electric atmospheres always become possessed of the electricity, contrary to that of the body, in whose atmosphere they are immerged."

existence without the expenditure of some other form of energy, any more than a steam-engine can work without fuel. As a matter of fact it is found that it is a little harder work to lift up the cover when it is charged than if it were not charged; for, when charged, there is the tension of the electric field to be overcome as well as the force of gravity. Slightly harder work is done at the expense of the muscular energies of the operator; and this is the real origin of the energy stored up in the separate charges. The purely mechanical actions of putting down the disk on the cake, touching it, and lifting it up, can be performed automatically by suitable mechanical arrangements, which render the production of these inductive charges practically continuous. Of such continuous electrophori, the latest is Wimshurst's machine, described in Lesson V.

27. **"Free" and "Bound" Electrification.** — We have spoken of a charge of electricity on the surface of a conductor, as being "bound" when it is attracted by the presence of a neighbouring charge of the opposite kind. The converse term "free" is sometimes applied to the ordinary state of electricity upon a charged conductor, not in the presence of a charge of an opposite kind. A "free" charge upon an insulated conductor flows away instantaneously to the earth, if a conducting channel be provided, as will be explained. It is immaterial what point of the conductor be touched. Thus, in the case represented in Fig. 17, wherein a + electrified body induces – electrification at the near end, and + electrification at the far end of an insulated conductor, the – charge is "bound," being attracted, while the + charge at the other end, being repelled, is "free"; and if the insulated conductor be touched by a person standing on the ground, the "free" charge will flow away through his body to the earth, or to the walls of the room, while the "bound" charge will remain, no matter whether he touch the conductor at the far end, or at the near end, or at the middle.

28. Method of charging the Gold-Leaf Electroscope by Influence.—The student will now be prepared to understand the method by which a Gold-Leaf Electroscope can be charged with the opposite kind of charge to that of the electrified body used to charge it. In Lesson II. it was assumed that the way to charge an electroscope was to place the excited body in contact with the knob, and thus permit, as it were, a small portion of the charge to flow into the gold leaves. A rod of glass rubbed on silk being + would thus obviously impart + electrification to the gold leaves.

Suppose, however, the rubbed glass rod to be held a few inches above the knob of the electroscope, as is indeed shown in Fig. 12. Even at this distance the gold leaves diverge, and the effect is due to influence. The gold leaves, and the brass wire and knob, form one continuous conductor, insulated from the ground by the glass jar. The presence of the + charge of the glass acts inductively on this "insulated conductor," inducing – electrification on the near end or knob, and inducing + at the far end, *i.e.* on the gold leaves, which diverge. Of these two induced charges, the – on the knob is "bound," while the + on the leaves is "free." If now, while the excited rod is still held above the electroscope, the knob be touched by a person standing on the ground, one of these two induced charges flows to the ground, namely, the free charge—not that on the knob itself, for it was "bound," but that on the gold leaves which was "free"—and the gold leaves instantly drop down straight. There now remains only the – charge on the knob, "bound" so long as the + charge of the glass rod is near to attract it. But if, finally, the glass rod be taken right away, the – charge is no longer "bound" on the knob, but is "free" to flow into the leaves, which once more diverge—but this time with a *negative* electrification.

29. The "Return-Shock."—It is sometimes noticed that, when a charged conductor is suddenly discharged,

a discharge is felt by persons standing near, or may even affect electroscopes, or yield sparks. This action, known as the "return-shock," is due to influence. For in the presence of a charged conductor a charge of opposite sign will be induced in neighbouring bodies, and on the discharge of the conductor these neighbouring bodies may also suddenly discharge their induced charge into the earth, or into other conducting bodies. A "return-shock" is sometimes felt by persons standing on the ground at the moment when a flash of lightning has struck an object some distance away.

Lesson IV. — *Conduction and Distribution of Electricity*

30. Conduction. — Toward the close of Lesson I. we explained how certain bodies, such as the metals, conduct electricity, while others are non-conductors or insulators. This discovery is due to Stephen Gray; who, in 1729, found that a cork, inserted into the end of a rubbed glass tube, and even a rod of wood stuck into the cork, possessed the power of attracting light bodies. He found, similarly, that metallic wire and pack-thread conducted electricity, while silk did not.

We may repeat these experiments by taking (as in Fig. 25) a glass rod, fitted with a cork and a piece of wood. If a bullet or a brass knob be hung to the end of this by a linen thread or a wire, it is found that when the glass tube is rubbed the bullet acquires the property of attracting light bodies. If a dry silk thread is used, however, no electricity will flow down to the bullet.

Gray even succeeded in transmitting a charge of electricity through a hempen thread over 700 feet long, suspended on silken loops. A little later Du Fay succeeded in sending electricity to no less a distance than 1256 feet through a moistened thread, thus proving the conducting power of moisture. From that time the

classification of bodies into *conductors* and *insulators* has been observed.

This distinction cannot, however, be entirely maintained, as a large class of substances occupy an intermediate ground as partial conductors. For example, dry wood is a bad conductor and also a bad insulator; it is a good enough conductor to conduct away the high-potential electricity obtained by friction, but it is a bad conductor for the relatively low-potential electricity of small voltaic batteries. Substances that are very bad

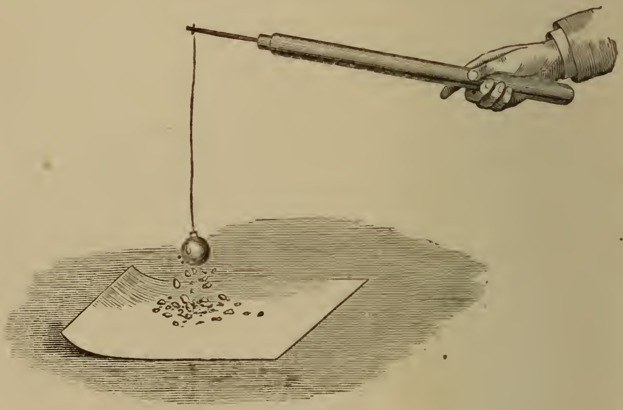

Fig. 25.

conductors are said to offer a great **resistance** to the flow of electricity through them. There is indeed no substance so good a conductor as to be devoid of resistance. There is no substance of so high a resistance as not to conduct a little. Even silver, which conducts best of all known substances, resists the flow of electricity to a small extent; and, on the other hand, such a non-conducting substance as glass, though its resistance is many million times greater than any metal, does allow a very small quantity of electricity to pass through it. In the

following list, the substances named are placed in order, each conducting better than those lower down on the list.

Silver . . .	**Good Conductors.**
Copper . . .	
Other metals .	
Charcoal . .	
Water . . .	
The body . .	**Partial Conductors.**
Cotton . . .	
Dry wood . .	
Marble . . .	
Paper . . .	
Oils	**Non-Conductors or Insulators.**
Porcelain . .	
Wool . . .	
Silk	
Resin . . .	
Guttapercha .	
Shellac . . .	
Ebonite . .	
Paraffin . .	
Glass . . .	
Quartz (fused)	
Air	

A simple way of observing experimentally whether a body is a conductor or not, is to take a charged gold-leaf electroscope, and, holding the substance to be examined in the hand, touch the knob of the electroscope with it. If the substance is a conductor the electricity will flow away through it and through the body to the earth, and the electroscope will be discharged. Through good conductors the rapidity of the flow is so great that the discharge is practically instantaneous. Further information on this question is given in Lesson XXXIII.

31. Distribution of Charge on Bodies. — If electrification is produced at one part of a non-conducting body, it remains at that point and does not flow over the surface, or at most flows over it excessively slowly.

Thus if a glass tube is rubbed at one end, only that one end is electrified. Hot glass is, however, a conductor. If a warm cake of resin be rubbed at one part with a piece of cloth, only the portion rubbed will attract light bodies, as may be proved by dusting upon it through a piece of muslin fine powders such as red lead, lycopodium, or verdigris, which adhere where the surface is electrified. The case is, however, wholly different when a charge of electricity is imparted to any part of a conducting body placed on an insulating support, for it *instantly* distributes itself all over the surface, though in general not uniformly over all points of the surface.

32. The Charge resides on the Surface. — A charge of electricity resides only on the surface of conducting bodies. This is proved by the fact that it is found to be immaterial to the distribution what the interior of a conductor is made of; it may be solid metal, or hollow, or even consist of wood covered with tinfoil or gilt, but, if the shape be the same, the charge will distribute itself precisely in the same manner over the surface. There are also several ways of proving by direct experiment this very important fact. Let a hollow metal ball, having an aperture at the top, be taken (as in Fig. 26), and set upon an insulating stem, and charged by sending into it a few sparks from an electrophorus. The absence of any charge in the interior may be shown as follows: — In order to observe the nature of the electrification of a charged body, it is convenient to have some means of removing a small quantity of the charge as a sample for examination. To obtain such a sample, a little instrument known as a **proof-plane** is employed. It consists of a little disk of sheet copper or of gilt paper fixed at the end of a small glass rod. If this disk is laid on the surface of an electrified body at any point, part of the charge flows into it, and it may be then removed, and the sample thus obtained may be examined with a gold-leaf electroscope in the ordinary way. For some

purposes a metallic bead, fastened to the end of a glass rod, is more convenient than a flat disk. If such a proof-plane be applied to the outside of our electrified hollow ball, and then touched on the knob of an electroscope, the gold leaves will diverge, showing the presence of a

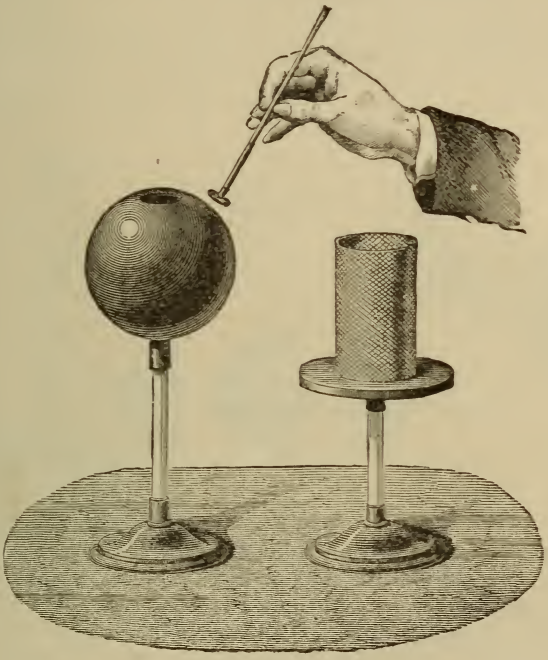

Fig. 26.

charge. But if the proof-plane be carefully inserted through the opening, and touched against the *inside* of the globe and then withdrawn, it will be found that the inside is destitute of electrification. An electrified pewter mug will show a similar result, and so will even a cylinder of gauze wire.

33. Biot's Experiment. — Biot proved the same fact in another way. A copper ball was electrified and insulated. Two hollow hemispheres of copper, of a larger size, and furnished with glass handles, were then placed together outside it (Fig. 27). So long as they did not come into contact the charge remained on the inner sphere; but if the outer shell touched the inner sphere for but an instant, the whole of the charge passed

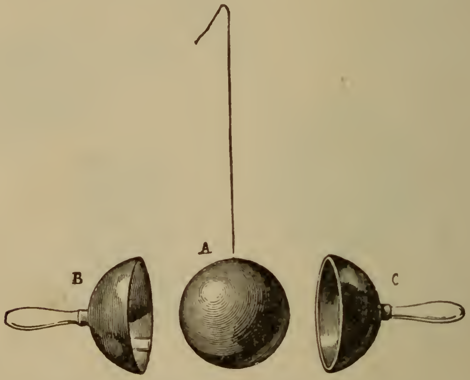

Fig. 27.

to the exterior; and when the hemispheres were separated and removed the inner globe was found to be completely discharged.

34. Further Explanation. — Doubtless the explanation of this behaviour of electricity is to be found in the property previously noticed as possessed by either kind of electrification, namely, that of repelling itself; hence it retreats as far as can be from the centre and remains upon the surface. An important proposition concerning the absence of electric force within a closed conductor is proved in Lesson XXI.; meanwhile it must be noted that the proofs, so far, are directed to demonstrate the absence

of a free charge of electricity in the interior of hollow conductors. Amongst other experiments, Terquem showed that a pair of gold leaves hung inside a wire cage could not be made to diverge when the cage was electrified. Faraday constructed a conical bag of linen-gauze, supported as in Fig. 28, upon an insulating stand, and to which silk strings were attached, by which it could be turned inside out. It was charged, and the charge was shown by the proof-plane and electroscope to be on the outside of the bag. On turning it inside out the elec-

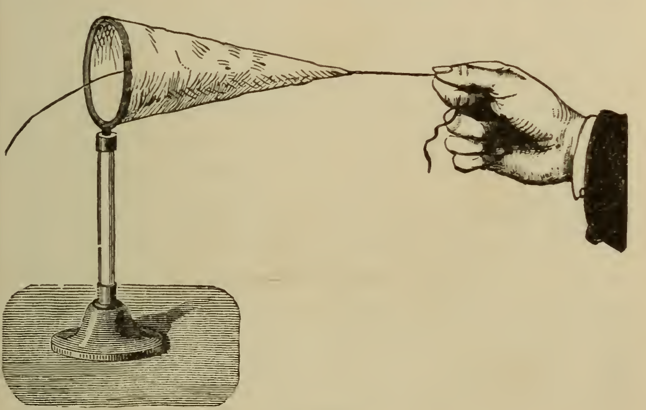

Fig. 28.

tricity was once more found *outside*. Faraday's most striking experiment was made with a hollow cube, measuring 12 feet each way, built of wood, covered with tinfoil, insulated, and charged with a powerful machine, so that large sparks and brushes were darting off from every part of its outer surface. Into this cube Faraday took his most delicate electroscopes; but once within he failed to detect the least effect upon them.

35. Applications. — Advantage is taken of this in the construction of delicate electrometers and other

instruments, which can be effectually screened from the influence of electrified bodies by enclosing them in a cover of thin metal, closed all round, except where apertures must be made for purposes of observation. Metal gauze answers excellently, and is nearly transparent. It was proposed by the late Professor Clerk Maxwell to protect buildings from lightning by covering them on the exterior with a network of wires.

36. Apparent Exceptions. — There are two apparent exceptions to the law that electrification resides only on the outside of conductors. (1) If there are electrified insulated bodies actually placed inside the hollow conductor, the presence of these electrified bodies acts inductively and attracts the opposite kind of charge to the inner side of the hollow conductor. (2) When electricity flows in a current, it flows through the substance of the conductor. The law is limited therefore to electricity at rest, — that is, to *statical* charges.

37. Faraday's "Ice-pail" Experiment. — One experiment of Faraday deserves notice, as showing the part played by induction in these phenomena. He gradually lowered a charged metallic ball into a hollow conductor connected by a wire to a gold-leaf electroscope (Fig. 29), and watched the effect. A pewter ice-pail being convenient for his purpose, this experiment is continually referred to by this name, though any other hollow conductor — a tin canister or a silver mug, placed on a glass support — would of course answer equally well. The following effects are observed: — Suppose the ball to have a + charge: as it is lowered into the hollow conductor the gold leaves begin to diverge, for the presence of the charge acts inductively, and attracts a – charge into the interior and repels a + charge to the exterior. The gold leaves diverge more and more until the ball is right within the hollow conductor, after which no greater divergence is obtained. On letting the ball touch the inside the gold leaves still remain diverging as

before, and if now the ball is pulled out it is found to have lost all its electrification. The fact that the gold leaves diverge no wider after the ball touched than they did just before, proves that when the charged ball is right inside the hollow conductor the induced charges are each of them precisely equal in amount to its own charge, and the interior negative charge exactly neutralizes the charge on the ball at the moment when they touch, leaving the equal exterior charge unchanged. An *electric cage*, such as this ice-pail, when connected with an electroscope or electrometer, affords an excellent means of examining the charge on a body small enough to be hung inside it. For without using up any of the charge of the body (which we are obliged to do when applying the method of the proof-plane) we can examine the induced charge repelled to the outside of the cage, which is equal in amount and of the same sign. If two equal charges of opposite kinds are placed at the same time within the cage no effects are produced on the outside.

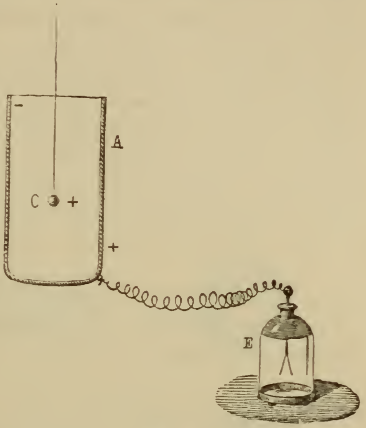

Fig. 29.

38. Distribution of Charge. — A charge of electricity is not usually distributed uniformly over the surfaces of bodies. Experiment shows that there is more electricity on the edges and corners of bodies than upon their flatter parts. This distribution can be deduced from the theory laid down in Lesson XXI., but meantime we will give some of the chief cases as they can be

shown to exist. The term **Electric Density** is used to signify the amount of electricity at any point of a surface; *the electric density at a point is the number of units of electricity per unit of area* (*i.e.* per square inch, or per square centimetre), the distribution being supposed uniform over this small surface.

(*a*) **Sphere.** — The distribution of a charge over an insulated sphere of conducting material is uniform, provided the sphere is also isolated, that is to say, is remote from the presence of all other conductors and all other electrified bodies. The density is uniform all over it. This is symbolized by the dotted line round the sphere

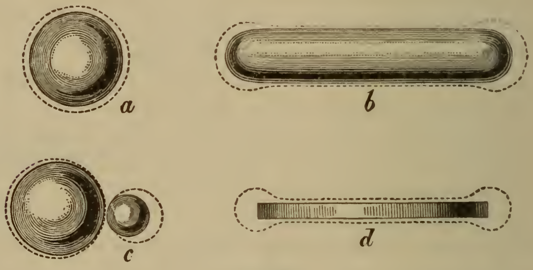

Fig. 30.

in Fig. 30 *a*, which is at an equal distance from the sphere all round, suggesting an equal thickness of charge at every point of the surface. It must be remembered that the charge is not really of any perceptible thickness at all; it resides on or at the surface, but cannot be said to form a stratum upon it.

(*b*) **Cylinder with rounded Ends.** — Upon an elongated conductor, such as is frequently employed in electrical apparatus, the density is greatest at the ends where the curvature of the surface is the greatest.

(*c*) **Two Spheres in contact.** — If two spheres in contact with each other are insulated and charged, it is found that the density is greatest at the parts farthest from the

point of contact, and least in the crevice between them. If the spheres are of unequal sizes the density is greater on the smaller sphere, which has the surface more curved. On an **egg-shaped** or **pear-shaped** conductor the density is greatest at the small end. On a **cone** the density is greatest at the apex; and if the cone terminate in a sharp point the density there is very much greater than at any other point. At a **point,** indeed, the density of the collected electricity may be so great as to electrify the neighbouring particles of air, which then are repelled (see Art. 47), thus producing a continual loss of charge. For this reason points and sharp edges are always avoided on electrical apparatus, except where it is specially desired to set up a discharge.

(*d*) **Flat Disk.** — The density of a charge upon a flat disk is greater, as we should expect, at the edges than on the flat surfaces; but over the flat surfaces the distribution is fairly uniform.

These various facts are ascertained by applying a small proof-plane successively at various points of the electrified bodies and examining the amount taken up by the proof-plane by means of an electroscope or electrometer. Coulomb, who investigated mathematically as well as experimentally many of the important cases of distribution, employed the torsion balance to verify his calculations. He investigated thus the case of the ellipsoid of revolution, and found the densities of the charges at the extremities of the axis to be proportional to the lengths of those axes. He also showed that the density of the charge at any other point of the surface of the ellipsoid was proportional to the length of the perpendicular drawn from the centre to the tangent at that point. Riess also investigated several interesting cases of distribution. He found the density at the middle of the edges of a cube to be nearly two and a half times as great as the density at the middle of a face; while the density at a corner of the cube was more than four times as great.

39. Redistribution of Charge. — If any portion of the charge of an insulated conductor be removed, the remainder of the charge will immediately redistribute itself over the surface in the same manner as the original charge, provided it be also *isolated*, *i.e.* that no other conductors or charged bodies be near to perturb the distribution by complicated effects of influence.

If a conductor be charged with any quantity of electricity, and another conductor of the same size and shape (but uncharged) be brought into contact with it for an instant and then separated, it will be found that the charge has divided itself equally between them. In the same way a charge may be divided equally into three or more parts by being distributed simultaneously over three or more equal and similar conductors brought into contact and symmetrically placed.

If two equal metal balls, suspended by silk strings, charged with unequal quantities of electricity, are brought for an instant into contact and then separated, it will be found that the charge has redistributed itself fairly, half the sum of the two charges being now the charge of each. This may even be extended to the case of charges of opposite signs. Thus, suppose two similar conductors to be electrified, one with a positive charge of 5 units and the other with 3 units of negative charge, when these are made to touch and separated, each will have a positive charge of 1 unit; for the algebraic sum of $+5$ and -3 is $+2$, which, shared between the two equal conductors, leaves $+1$ for each.

40. Capacity of Conductors. — If the conductors be unequal in size, or unlike in form, the shares taken by each in this redistribution will not be equal, but will be proportional to the electric *capacities* of the conductors. The definition of **capacity** in its relation to electric quantities is given in Lesson XXI., Art. 271. We may, however, make the remark, that two insulated conductors of the same form, but of different sizes, differ in their

electrical *capacity;* for the larger one must have a larger amount of electricity imparted to it in order to electrify its surface to the same degree. The term *potential* is employed in this connexion, in the following way:—A given quantity of electricity will electrify an isolated body up to a certain "potential" (or power of doing electric work) depending on its capacity. A large *quantity* of electricity imparted to a conductor of small *capacity* will electrify it up to a very high *potential;* just as a large quantity of water poured into a vessel of narrow capacity will raise the surface of the water to a high level in the vessel. The exact definition of Potential, in terms of energy spent against the electrical forces, is given in the lesson on Electrostatics (Art. 263).

It will be found convenient to refer to a positively electrified body as one electrified to a *positive or high potential;* while a negatively electrified body may be looked upon as one electrified to a *low or negative potential.* And just as we take the level of the sea as a zero level, and measure the heights of mountains above it, and the depths of mines below it, using the sea level as a convenient point of reference for differences of level, so we take the potential of the earth's surface (for the surface of the earth is always electrified to a certain degree) as *zero potential,* and use it as a convenient point of reference from which to measure differences of electric potential.

Lesson V.—*Electric Machines*

41. For the purpose of procuring larger supplies of electricity than can be obtained by the rubbing of a rod of glass or shellac, **electric machines** have been devised. All electric machines consist of two parts, one for producing, the other for collecting, the electric charges. Experience has shown that the quantities of + and − elec-

trification developed by friction upon the two surfaces rubbed against one another depend on the amount of friction, upon the extent of the surfaces rubbed, and also upon the nature of the substances used. If the two substances employed are near together on the list of electrics given in Art. 6, the electrical effect of rubbing them together will not be so great as if two substances widely separated in the series are chosen. To obtain the highest effect, the most positive and the most negative of the substances convenient for the construction of a machine should be taken, and the greatest available surface of them should be subjected to friction, the moving parts having a sufficient pressure against one another compatible with the required velocity.

The earliest form of electric machine was devised by Otto von Guericke of Magdeburg, and consisted of a globe of sulphur fixed upon a spindle, and pressed with the dry surface of the hands while being made to rotate; with this he discovered the existence of electric sparks and the repulsion of similarly electrified bodies. Sir Isaac Newton replaced Von Guericke's globe of sulphur by a globe of glass. A little later the form of the machine was improved by various German electricians; Von Bose added a collector or "prime conductor," in the shape of an iron tube, supported by a person standing on cakes of resin to insulate him, or suspended by silken strings; Winckler of Leipzig substituted a leathern cushion for the hand as a rubber; and Gordon of Erfurt rendered the machine more easy of construction by using a glass cylinder instead of a glass globe. The electricity was led from the excited cylinder or globe to the prime conductor by a metallic chain which hung over against the globe. A pointed collector was not employed until after Franklin's famous researches on the action of points. About 1760 De la Fond, Planta, Ramsden, and Cuthbertson, constructed machines having glass plates instead of cylinders. All frictional machines are, however, now

obsolete, having in recent years been quite superseded by the modern *Influence Machines*.

42. The Cylinder Electric Machine. — The Cylinder Electric Machine consists of a glass cylinder mounted on a horizontal axis capable of being turned by a handle. Against it is pressed from behind a cushion of leather stuffed with horsehair, the surface of which is covered with a powdered amalgam of zinc or tin. A flap of silk attached to the cushion passes over the cylinder, covering its upper half. In front of the cylinder stands the "prime conductor," which is made of metal, and usually

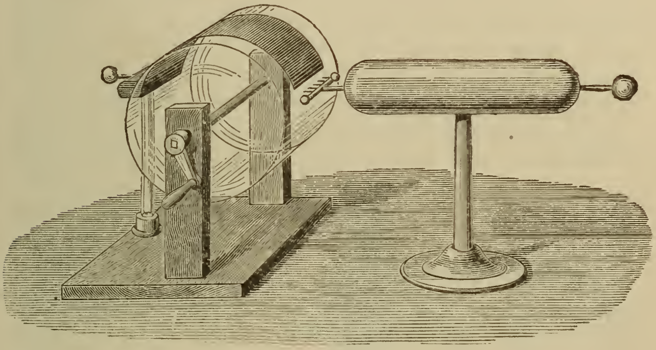

Fig. 31.

of the form of an elongated cylinder with hemispherical ends, mounted upon a glass stand. At the end of the prime conductor nearest the cylinder is fixed a rod bearing a row of fine metallic spikes, resembling in form a rake; the other end usually carries a rod terminated in a brass ball or knob. The general aspect of the machine is shown in Fig. 31. When the handle is turned the friction between the glass and the amalgam-coated surface of the rubber produces a copious electrical action, electricity appearing as a + charge on the glass, leaving the rubber with a – charge. The prime conductor col-

lects this charge by the following process: — The + charge being carried round on the glass acts inductively on the long insulated conductor, repelling a + charge to the far end; leaving the nearer end – ly charged. The effect of the row of points is to emit a – ly electrified wind (see Art. 47) towards the attracting + charge upon the glass, which is neutralized thereby; the glass thus arriving at the rubber in a neutral condition ready to be again excited. This action of the points is sometimes described, though less correctly, by saying that the points collect the + charge from the glass. If it is desired to collect also the – charge of the rubber, the cushion must be supported on an insulating stem and provided at the back with a metallic knob. It is, however, more usual to use only the + charge, and to connect the rubber by a chain to "earth," so allowing the – charge to be neutralized.

43. The Plate Electric Machine. — The Plate Machine, as its name implies, is constructed with a circular plate of glass or of ebonite, and is usually provided with two pairs of rubbers formed of double cushions, pressing the plate between them, placed at its highest and lowest point, and provided with silk flaps, each extending over a quadrant of the circle. The prime conductor is either double or curved round to meet the plate at the two ends of its horizontal diameter, and is furnished with two sets of spikes, for the same purpose

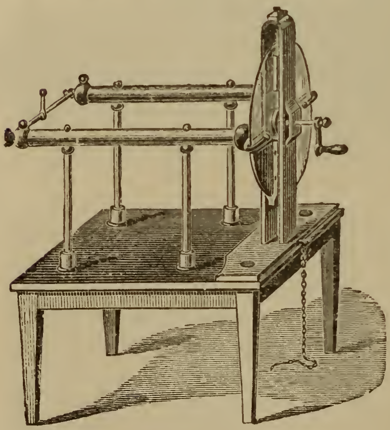

Fig. 32.

as the row of points in the cylinder machine. A common form of plate machine is shown in Fig. 32. The action of the machine is, in all points of theoretical interest, the same as that of the cylinder machine. Its advantages are that a large glass plate is more easy to construct than a large glass cylinder of perfect form, and that the length along the surface of the glass between the collecting row of points and the edge of the rubber cushions is greater in the plate than in the cylinder for the same amount of surface exposed to friction; for, be it remarked, when the two charges thus separated have collected to a certain extent, a discharge will take place along this surface, the length of which limits therefore the power of the machine. In a more modern form, due to Le Roy, and modified by Winter, there is but one rubber and flap, occupying a little over a quadrant of the plate, and one collector or double row of points, while the prime conductor consists of a ring-shaped body.

44. Electric Amalgam. — Canton, finding glass to be highly electrified when dipped into dry mercury, suggested the employment of an amalgam of tin with mercury as a suitable substance wherewith to cover the surface of the rubbers. Still better is Kienmayer's amalgam, consisting of equal parts of tin and zinc, mixed while molten with twice their weight of mercury. Bisulphide of tin ("mosaic gold") may also be used. These amalgams are applied to the cushions with a little stiff grease. They serve the double purpose of conducting away the negative charge separated upon the rubber during the action of the machine, and of affording as a rubber a substance which is more powerfully negative (see list in Art. 6) than the leather or the silk of the cushion itself. Powdered graphite is also good.

45. Precautions in using Frictional Machines. — Several precautions must be observed in the use of electrical machines. Damp and dust must be scrupulously avoided. The surface of glass is hygroscopic, hence,

except in the driest climates, it is necessary to warm the glass surfaces and rubbers to dissipate the film of moisture which collects. Glass stems for insulation may be varnished with a thin coat of shellac varnish, or with paraffin (solid). A few drops of anhydrous paraffin (obtained by dropping a lump of sodium into a bottle of paraffin oil), applied with a bit of flannel to the previously warmed surfaces, hinders the deposit of moisture. A frictional machine which has not been used for some months will require a fresh coat of amalgam on its rubbers. These should be cleaned and warmed, a thin uniform layer of tallow or other stiff grease is spread upon them, and the amalgam, previously reduced to a fine powder, is sifted over the surface. In spite of all precautions friction machines are uncertain in their behaviour in damp weather. This is the main reason why they have been superseded by influence machines, which do not need to be warmed.

All **points** should be avoided in apparatus for frictional electricity except where they are desired, like the "collecting" spikes on the prime conductor, to let off a charge of electricity. All the rods, etc., in frictional apparatus are therefore made with rounded knobs.

46. Experiments with the Electric Machine. — With the electric machine many pleasing and instructive experiments are possible. The phenomena of *attraction and repulsion* can be shown upon a large scale. Fig. 33 represents a device known as the **electric chimes**,* in which two small brass balls hung by silk strings are set in motion and strike against the bells between which they are hung. The two outer bells are hung by metallic wires or chains to the knob of the machine. The third bell is hung by a silk thread, but communicates with the ground by a brass chain. The balls are first attracted to

* Invented in 1752 by Franklin, for the purpose of warning him of the presence of atmospheric electricity, drawn from the air above his house by a pointed iron rod.

the electrified outer bells, then repelled, and, having discharged themselves against the uninsulated central bell, are again attracted, and so vibrate to and fro.

By another arrangement small figures or dolls cut out of pith can be made to dance up and down between a metal plate hung horizontally from the knob of the machine, and another flat plate an inch or two lower and communicating with "earth."

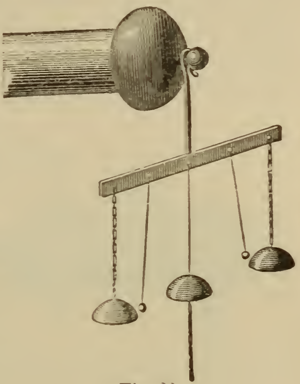

Fig. 33.

Another favourite way of exhibiting electric repulsion is by means of a doll with long hair placed on the machine; the individual hairs stand on end when the machine is worked, being repelled from the head, and from one another. A paper tassel will behave similarly if hung to the prime conductor. The most striking way of showing this phenomenon is to place a person upon a glass-legged stool, making him touch the knob of the machine; when the machine is worked, his hair, if dry, will stand on end. Sparks will pass freely between a person thus electrified and one standing upon the ground.

The sparks from the machine may be made to kindle spirits of wine or ether, placed in a metallic spoon, connected by a wire, with the nearest metallic conductor that runs into the ground. A gas jet may be lit by passing a spark to the burner from the finger of the person standing, as just described, upon an insulating stool.

47. Effect of Points; Electric Wind. — The *effect of points* in discharging electricity from the surface of a conductor may be readily proved by numerous experiments.

If the machine be in good working order, and capable of giving, say, sparks 4 inches long when the knuckle is presented to the knob, it will be found that, on fastening a fine pointed needle to the conductor, it discharges the electricity so effectually at its point that only the shortest sparks can be drawn at the knob, while a fine jet or brush of pale blue light will appear at the point. If a lighted taper be held in front of the point, the flame will be visibly blown aside (Fig. 34) by the streams of electrified air repelled from the point. These air-currents can be

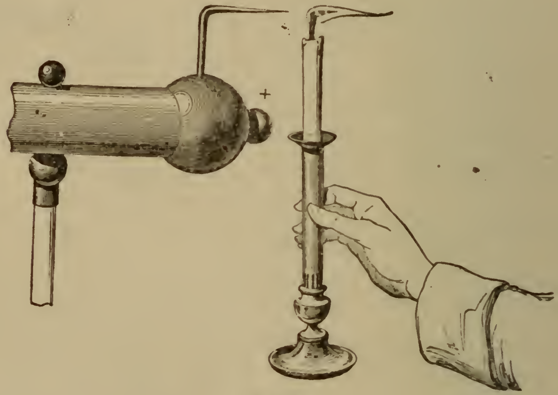

Fig. 34.

felt with the hand. They are due to a mutual repulsion between the electrified air particles near the point and the electricity collected on the point itself. That this mutual *reaction* exists is proved by the **electric fly** or **electric reaction-mill** of Hamilton (Fig. 35), which consists of a light cross of brass or straw, suspended on a pivot, and having the pointed ends bent round at right angles. When placed on the prime conductor of the machine, or joined to it by a chain, the force of repulsion between the electricity of the points and that on the air

immediately in front of them drives the mill round in the direction opposite to that in which the points are bent. It will even rotate if immersed in turpentine or petroleum. If the points of the fly are covered with small round lumps of wax it will not rotate, as the presence of the wax prevents the formation of any wind or stream of electrified particles.

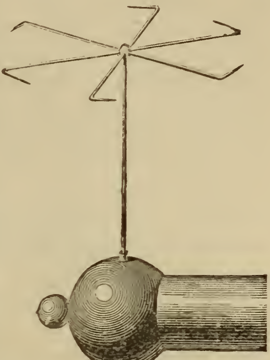

Fig. 35.

The electric wind from a point will produce a charge upon the surface of any insulating body, such as a plate of ebonite or glass, held a few inches away. The charge may be examined by dusting red lead or lycopodium powder upon the surface. If a slip of glass or mica be interposed between the point and the surface against which the wind is directed, an electric *shadow* will be formed on the surface at the part so screened.

48. Armstrong's Hydro-Electrical Machine. — The friction of a jet of steam issuing from a boiler, through a wooden nozzle, generates electricity. In reality it is the particles of condensed water in the jet which are directly concerned. Sir W. Armstrong, who investigated this source of electricity, constructed a powerful apparatus, known as the **hydro-electrical machine,** capable of producing enormous quantities of electricity, and yielding sparks 5 or 6 feet long. The collector consisted of a row of spikes, placed in the path of the steam jets issuing from wooden nozzles, and was supported, together with a brass ball which served as prime conductor, upon a glass pillar.

49. Influence Machines. — There is another class of

electrical machine, differing entirely from those we have been describing, and depending upon the principle of *influence.* They also have been termed *convection-induction machines*, because they depend upon the employment of a minute initial charge which, acting by influence, *induces* other charges, which are then *conveyed* by the moving parts of the machine to some other part, where they can be used either to increase the initial charge or to furnish a supply of electrification to a suitable collector. Of such instruments the oldest is the *Electrophorus*, explained fully in Lesson III. Bennet, Nicholson, Erasmus Darwin, and others devised pieces of apparatus for accomplishing by mechanism that which the electrophorus accomplishes by hand. Nicholson's *revolving doubler*, invented in 1788, consists of a revolving apparatus, in which an insulated carrier can be brought into the presence of an electrified body, there touched for an instant while under influence, then carried forward with its acquired charge towards another body, to which it imparts its charge, and which in turn acts inductively on it, giving it an opposite charge, which it can convey to the first body, thus increasing its initial charge at every rotation.

In the modern influence machines two principles are embodied: (1) the principle of *influence*, namely, that a conductor touched while under influence acquires a charge of the opposite kind; (2) the principle of *reciprocal accumulation.* This principle must be carefully noted. Let there be two insulated conductors A and B electrified ever so little, one positively, the other negatively. Let a third insulated conductor C, which will be called a *carrier*, be arranged to move so that it first approaches A and then B, and so forth. If touched while under the influence of the small positive charge on A it will acquire a small negative charge; suppose that it then moves on and gives this negative charge to B. Then let it be touched while under the influence of B, so acquiring a small positive charge. When it returns towards A let it give

up this positive charge to A, thereby increasing its positive charge. Then A will act more powerfully, and on repeating the former operations both B and A will become more highly charged. Each accumulates the charges derived by influence from the other. This is the fundamental action of the machines in question. The modern influence machines date from 1860, when C. F. Varley produced a form with six carriers mounted on a rotating disk of glass. This was followed in 1865 by

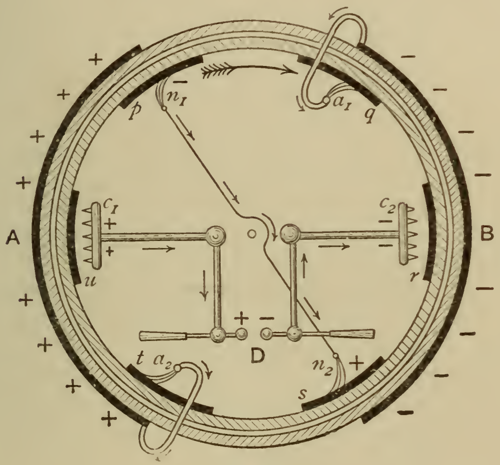

Fig. 36.

the machine of Holtz and that of Toepler, and in 1867 by those of Lord Kelvin (the "replenisher" and the "mouse-mill"). The latest forms are those of Mr. James Wimshurst.

50. Typical Construction. — Before describing some special forms we will deal with a generalized type of machine having two fixed *field-plates*, A and B, which are to become respectively + and −, and a set of *carriers*, attached to a rotating disk or *armature*. Fig. 36 gives in

a diagrammatic way a view of the essential parts. For convenience of drawing it is shown as if the metal field-plates A and B were affixed to the outside of an outer stationary cylinder of glass; the six carriers p, q, r, s, t, and u being attached to the inside of an inner rotating cylinder. The essential parts then are as follows: —

(i.) A pair of *field-plates* A and B.

(ii.) A set of *rotating carriers* p, q, r, s, t, and u.

(iii.) A pair of *neutralizing brushes* n_1, n_2 made of flexible metal wires, the function of which is to touch the carriers while they are under the influence of the field-plates. They are connected together by a *diagonal conductor*, which need not be insulated.

(iv.) A pair of *appropriating brushes* a_1, a_2, which reach over from the field-plates to appropriate the charges that are conveyed around by the carriers, and impart them to the field-plates.

(v.) In addition to the above, which are sufficient to constitute a complete self-exciting machine, it is usual to add a *discharging apparatus*, consisting of two *combs* c_1, c_2, to collect any unappropriated charges from the carriers after they have passed the appropriating brushes; these combs being connected to the adjustable discharging balls at D.

The operation of the machine is as follows. The neutralizing brushes are set so as to touch the moving carriers just before they pass out of the influence of the field-plates. Suppose the field-plate A to be charged ever so little positively, then the carrier p, touched by n_1 just as it passes, will acquire a slight negative charge, which it will convey forward to the appropriating brush a_1, and will thus make B slightly negative. Each of the carriers as it passes to the right over the top will do the same thing. Similarly each of the carriers as it passes from

right to left at the lower side will be touched by n_2 while under the influence of the $-$ charge on B, and will convey a small $+$ charge to A through the appropriating brush a_2. In this way A will rapidly become more and more $+$, and B more and more $-$; and the more highly charged they become, the more do the collecting combs c_1 and c_2 receive of unappropriated charges. Sparks will snap across between the discharging knobs at D.

The machine will not be self-exciting unless there is a good metallic contact made by the neutralizing brushes and by the appropriating brushes. If the discharging apparatus were fitted at c_1, c_2 with contact brushes instead of spiked combs, the machine would be liable to lose the charge of the field-plates, or even to have their charges reversed in sign whenever a large spark was taken from the knobs.

It will be noticed that there are two thicknesses of glass between the fixed *field-plates* and the rotating *carriers*. The glass serves not only to hold the metal parts, but prevents the possibility of back-discharges (by sparks or winds) from the carriers to the field-plates as they pass.

The essential features thus set forth will be found in Varley's machine of 1860, in Lord Kelvin's "replenisher" (which had only two carriers), and in many other machines including the apparatus known as Clarke's "gas-lighter."

51. Toepler's Influence Machine. — In this machine, as constructed by Voss, are embodied various points due to Holtz and others. Its construction follows almost literally the diagram already explained, but instead of having two cylinders, one inside the other, it has two flat disks of varnished glass, one fixed, the other slightly smaller rotating in front of it (Fig. 37). The *field-plates* A and B consist of pieces of tinfoil, cemented on the back of the back disk, each protected by a coating of varnished paper. The *carriers* are small disks or sectors of tinfoil, to the number of six or eight, cemented to the front of the front disk. To prevent them from being worn away by rubbing against the brushes a small

metallic button is attached to the middle of each. The neutralizing brushes n_1, n_2 are small whisps of fine springy brass wire, and are mounted on the ends of a diagonal conductor Z. The appropriating brushes a_1, a_2 are also of thin brass wire, and are fastened to clamps projecting from the edge of the fixed disk, so that they communicate metallically with the two field-plates. The collecting combs, which have brass spikes so short as not to touch the carriers, are mounted on insulating pillars and are connected to the adjustable discharging knobs

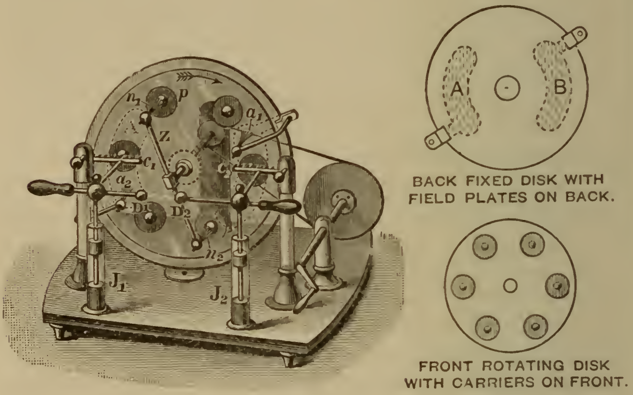

Fig. 37.

D_1, D_2. These also communicate with two small Leyden jars J_1, J_2, the function of which is to accumulate the charges before any discharge takes place. These jars are separately depicted in Fig. 38. Without them, the discharges between the knobs take place in frequent thin blue sparks. With them the sparks are less numerous, but very brilliant and noisy.

To use the Toepler (Voss) machine first see that all the four brushes are so set as to make good metallic contact with the carriers as they move past, and that the

neutralizing brushes are set so as to touch the carriers while under influence. Then see that the discharging knobs are drawn widely apart. Set the machine in rotation briskly. If it is clean it should excite itself after a couple of turns, and will emit a gentle hissing sound, due to internal discharges (visible as blue glimmers in the dark), and will offer more resistance to turning. If then the knobs are pushed nearer together sparks will pass across between them. The jars (the addition of which we owe to Holtz) should be kept free from dust. Sometimes a pair of terminal screws are added at S_1, S_2 (Fig. 38), connected respectively with the outer coatings

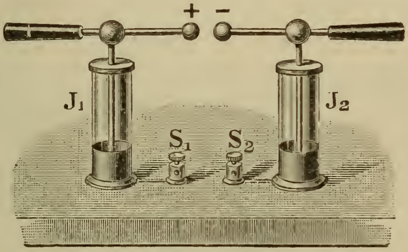

Fig. 38.

of the jars. These are convenient for attaching wires to lead away discharges for experiments at a distance. If not so used they should be joined together by a short wire, as the two jars will not work properly unless their outer coatings are connected.

52. Wimshurst's Influence Machine. — In this, the most widely used of influence machines, there are no fixed field-plates. In its simplest form it consists (Fig. 39) of two circular plates of varnished glass, which are geared to rotate in opposite directions. A number of sectors of metal foil are cemented to the front of the front plate and to the back of the back plate; these sectors serve both as carriers and as inductors. Across

the front is fixed an uninsulated diagonal conductor, carrying at its ends neutralizing brushes, which touch the front sectors as they pass. Across the back, but sloping the other way, is a second diagonal conductor, with brushes that touch the sectors on the hinder plate. Nothing more than this is needed for the machine to excite itself when set in rotation; but for convenience

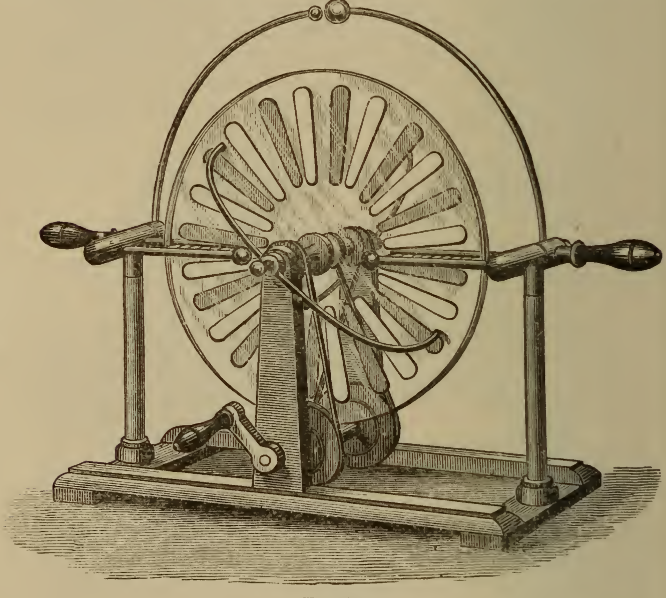

Fig. 39.

there is added a collecting and discharging apparatus. This consists of two pairs of insulated combs, each pair having its spikes turned inwards toward the revolving disks, but not touching them; one pair being on the right, the other on the left, mounted each on an insulating pillar of ebonite. These collectors are furnished with a pair of adjustable discharging knobs overhead;

and sometimes a pair of Leyden jars is added, to prevent the sparks from passing until considerable quantities of charge have been collected.

The processes that occur in this machine are best explained by aid of a diagram (Fig. 40), in which, for greater clearness, the two rotating plates are represented

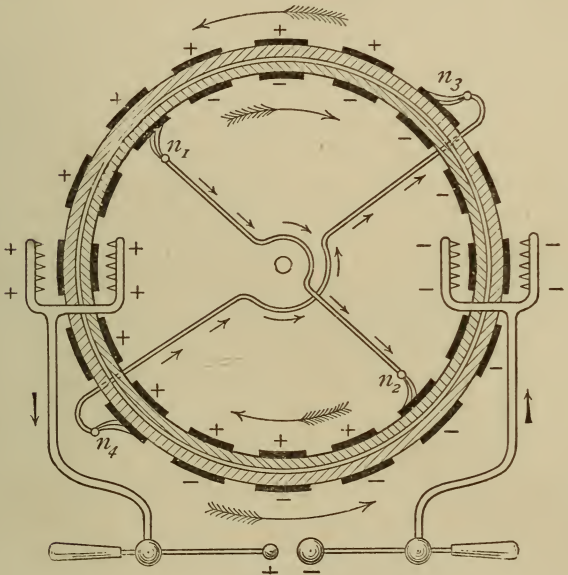

Fig. 40.

as though they were two cylinders of glass, rotating opposite ways, one inside the other. The inner cylinder will represent the front plate, the outer the back plate. In Figs. 39 and 40 the front plate rotates right-handedly, the back plate left-handedly. The neutralizing brushes n_1, n_2 touch the front sectors, while n_3, n_4 touch against the back sectors.

Now suppose any one of the back sectors represented near the top of the diagram to receive a slight positive charge. As it is moved onward toward the left it will come opposite the place where one of the front sectors is moving past the brush n_1. The result will be that the sector so touched while under influence by n_1 will acquire a slight negative charge, which it will carry onwards toward the right. When this negatively-charged front sector arrives at a point opposite n_3 it acts inductively on the back sector which is being touched by n_3; hence this back sector will in turn acquire a positive charge, which it will carry over to the left. In this way all the sectors will become more and more highly charged, the front sectors carrying over negative charges from left to right, and the back sectors carrying over positive charges from right to left. At the lower half of the diagram a similar but inverse set of operations will be taking place. For when n_1 touches a front sector under the influence of a positive back sector, a repelled charge will travel along the diagonal conductor to n_2, helping to charge positively the sector which it touches. The front sectors, as they pass from right to left (in the lower half), will carry positive charges, while the back sectors, after touching n_4, will carry negative charges from left to right. The metal sectors then act both as carriers and as inductors. It is clear that there will be a continual carrying of positive charges toward the right, and of negative charges to the left. At these points, toward which the opposite kinds of charges travel, are placed the collecting-combs communicating with the discharging knobs. The latter ought to be opened wide apart when starting the machine, and moved together after it has excited itself.

In larger Wimshurst influence machines two, three, or more pairs of oppositely-rotating plates are mounted within a glass case to keep off the dust. If the neutralizing brushes make good metallic contact these machines are all self-exciting in all weathers. Machines with only

six or eight sectors on each plate give longer sparks, but less frequently than those that have a greater number. Mr. Wimshurst has designed many influence machines, from small ones with disks 2 inches across up to that at South Kensington, which has plates 7 feet in diameter.

Prior to Wimshurst's machine Holtz had constructed one with two oppositely-rotating glass disks; but they had no metal carriers upon them. It was not self-exciting.

53. **Holtz's Influence Machine.** — The Holtz machine in its typical form had the following peculiarities. There were no metal carriers upon the rotating plate, hence another mode of charging it had to be adopted in lieu of touching conductors while under influence, as will be seen. The field-plates A and B (Fig. 41) were of varnished paper — a poor conductor — fastened upon the back of the fixed disk. In the fixed disk of glass, on which the field-plates were mounted, there were cut two windows or openings, through which there projected from the field-plates two pointed paper tongues, which took the place of appropriating brushes. The discharging knobs were inserted in the neutralizing circuit which united two metal combs with pointed spikes, situated in front of the rotating front disk, opposite the two field-plates. There was (at first) no diagonal conductor. It will be noted that while the combs, which served both as neutralizing and collecting combs, were in front of the rotating plate, the appropriating tongues were situated at the back of the same. Fig. 41 is a view of the machine from behind. The machine was not self-exciting. In operating it the following procedure

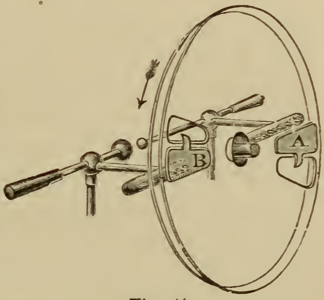

Fig. 41.

was used: first the two discharging knobs were put together, then the front disk was set into rapid rotation. While so rotating a small initial charge was communicated to one of the field-plates by holding to it a rubbed piece of ebonite or glass, or by sending into it a spark from a Leyden jar. Thereupon the machine charged itself, and began to emit pale blue sparks from the points of the combs and tongues with a hissing sound. On then drawing apart the discharging knobs, a torrent of sparks rushed across.

These arrangements being known, it is not difficult to follow the action of the machine, provided it is once understood that the whole operation depends upon the circumstance that the surface of a non-conducting body such as glass can be electrified by letting off against it an electric wind from a point placed near it (see Art. 47). Suppose that a small initial + charge is given to A. This will operate by influence upon the metal parts immediately opposite it, and cause the spikes to become electrified negatively, and to give off a negatively electrified wind, which will charge the face of the rotating plate, these charges being then carried over to the other side, where the spikes of the other comb will be emitting a positively electrified wind. The pointed tongues which project towards the back of the rotating disk also let off winds, the tendency being always for them to charge the back of the plate with a charge of opposite sign from that which is coming toward them on the front. If negative charges are being carried over the top on the front, then the tongue of B will tend to let off a positive charge against the back, thereby leaving B more negative. In the same way the tongue of A will let off a negatively electrified wind, making A more positive, so building up or accumulating two opposite kinds of charges on the two field-plates. This action will not occur unless the moving plate rotates in the direction opposite to that in which the two tongues point.

The defects of the Holtz machine were that it was so sensitive to damp weather as to be unreliable, that it was apt suddenly to reverse its charges, and that the electric winds by which it operated could not be produced without a sufficiently great initial charge.

In later Holtz machines a number of rotating disks fixed upon one common axis were employed, the whole being enclosed in a glass case to prevent the access of damp. A small disk of ebonite was sometimes fixed to the same axis, and provided with a rubber, in order to keep up the initial charge by friction. Holtz constructed many forms of machine, including one with thirty-two plates, besides machines of a second kind having two glass plates rotating in opposite directions.

The Holtz machine, as indeed every kind of influence machine, is *reversible* in its action; that is to say, that if a continuous supply of the two electricities (furnished by another machine) be communicated to the armatures, the movable plate will be thereby set in rotation and, if allowed to run quite freely, will turn in an opposite sense.

Righi showed that a Holtz machine can yield a continuous current like a voltaic battery, the strength of the current being nearly proportional to the velocity of rotation. It was found that the electromotive-force of a machine was equal to that of 52,000 Daniell's cells, or nearly 53,000 volts, at all speeds. The resistance when the machine made 120 revolutions per minute was 2810 million ohms; but only 646 million ohms when making 450 revolutions per minute.

54. Experiments with Influence Machines. — The experiments described in Art. 43, and indeed all those usually made with the old frictional machines, including the charging of Leyden jars, can be performed by the aid of influence machines. In some cases it is well to connect one of the two discharging knobs to the earth by a wire or chain, and to take the discharge from the other knob. To illuminate small vacuum tubes they

may be connected by guttapercha-covered wires to the two discharging knobs, or to the terminals S_1, S_2 of Fig. 38. The curious property of the electric discharge from a point in collecting *dust* or fumes is readily shown by connecting by a wire a needle which is introduced into a bell-jar of glass. The latter is filled with fumes by burning inside it a bit of magnesium wire, or of brown paper. Then on turning the handle of the influence machine the fumes are at once deposited, and the air left clear.

Lesson VI. — *The Leyden Jar and other Condensers*

55. It was shown in previous lessons that the opposite charges of electricity attract one another; that electricity cannot flow through glass; and that yet electricity can *act across* glass by influence. Two suspended pith-balls, one electrified positively and the other negatively, will attract one another across the intervening air. If a plate of glass be put between them they will still attract one another, though neither they themselves nor the electric charges on them can pass through the glass. If a pith-ball electrified with a – charge be hung inside a dry glass bottle, and a rubbed glass rod be held outside, the pith-ball will rush to the side of the bottle nearest to the glass rod, being attracted by the + charge thus brought near it. If a pane of glass be taken, and a piece of tinfoil be stuck upon the middle of each face of the pane, and one piece of tinfoil be charged positively, and the other negatively, the two charges will attract one another across the glass, and will no longer be found to be free. If the pane is set up on edge, so that neither piece of tinfoil touches the table, it will be found that hardly any electricity can be got by merely touching either of the foils, for the charges are "bound," so to speak, by each other's attractions; each charge is inducing the other. In fact it will be

found that these two pieces of tinfoil may be, in this manner, charged a great deal more strongly than either of them could possibly be if it were stuck to a piece of glass alone, and then electrified. In other words, *the capacity of a conductor is greatly increased when it is placed near to a conductor electrified with the opposite kind of charge.* If its capacity is increased, a greater quantity of electricity may be put into it before it is charged to an equal degree of potential. Hence, such an arrangement for holding a large quantity of electrification may be called a **condenser** of electricity.

56. Condensers. — Next, suppose that we have two brass disks, A and B (Fig. 42), set upon insulating stems, and that a glass plate is placed between them. Let B be connected by a wire to the knob of an electrical machine, and let A be joined by a wire to "earth." The + charge upon B will act inductively across the glass plate on A, and will repel electricity into the earth, leaving the nearest face of A negatively electrified. This − charge on A will attract the + charge of B to the side nearest the glass, and a fresh supply of electricity will come from the machine. Thus this arrangement will become a condenser. If the two brass disks are pushed up close to the glass plate there will be a still stronger attraction between the + and − charges, because they are now nearer one another, and the inductive action will be greater; hence a still larger quantity can be accumulated in the plates. We see then that the capacity of a condenser is increased by bringing the plates near together. If now, while the disks are strongly charged, the wires are removed and the

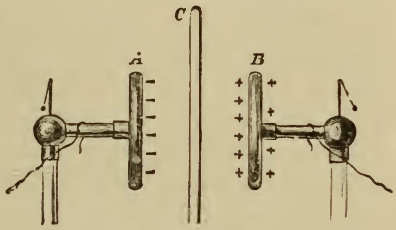

Fig. 42.

disks are drawn backwards from one another, the two charges will not hold one another bound so strongly, and there will be more *free* electrification than before over their surfaces. This would be rendered evident to the experimenter by the little pith-ball electroscopes fixed to them (see the Fig.), which would fly out as the brass disks were moved apart. We have put no further charge on the disk B, and yet, from the indications of the electroscope, we should conclude that by moving it away from disk A it has become electrified to a higher degree. The fact is, that while the conductor B was near the – charge of A the *capacity* of B was greatly increased, but on moving it away from A its capacity has diminished, and hence the same quantity of electricity now electrifies it to a higher degree than before. The presence, therefore, of an earth-connected plate near an insulated conductor increases its capacity, and permits it to accumulate a greater charge by attracting and *condensing* the electricity upon the face nearest the earth-plate, the surface-density on this face being therefore very great; hence the appropriateness of the term *condenser* as applied to the arrangement. It was formerly also called an **accumulator**; but the term *accumulator* is now reserved for the special kind of battery for storing the energy of electric currents (Art. 492).

The stratum of *air* between the two disks will suffice to insulate the two charges one from the other. The brass disks thus separated by a stratum of air constitute an **air-condenser**, or **air-leyden**. Such condensers were first devised by Wilcke and Aepinus. In these experiments the sheet of glass or layer of air acts as a *dielectric* (Art. 295) conveying the inductive action through its substance. All dielectrics are insulators, but equally good insulators are not necessarily equally good dielectrics. Air and glass are far better insulators than ebonite or paraffin in the sense of being much worse conductors. But influence acts more strongly across a slab of glass than across a slab of ebonite or paraffin of equal thickness,

and better still across these than across a layer of air. In other words, glass is a better **dielectric** than ebonite, or paraffin, or air, as it possesses a higher inductive capacity.

It will then be seen that in the act of charging a condenser, as much electricity flows out at one side as flows in at the other.

57. Displacement. — Whenever electric forces act on a dielectric, tending to drive electricity in at one side and out at the other, we may draw lines of force through the dielectric in the direction of the action, and we may consider tubular spaces mapped out by such lines. We may consider a tube of electric force having at one end a definite area of the positively charged surface, and at the other end an area of the negatively charged surface. These areas may be of different size or shape, but the quantities of + and − electrification over them will be equal. The quantity of electricity which has apparently been transferred along the tube was called by Maxwell "the *displacement*." In non-conductors it is proportional to the electromotive-force. In conductors electromotive forces produce currents, which may be regarded as displacements which increase continuously with time. In certain crystalline media the displacement does not take place exactly in the direction of the electric force: in this case we should speak of tubes of influence rather than tubes of force. A unit tube will be bounded at its two ends by unit charges + and −. We may consider the whole electric field between positively and negatively charged bodies as mapped out into such tubes.

58. Capacity of a Condenser. — It appears, therefore, that the capacity of a condenser will depend upon —

(1) The size and form of the metal plates or coatings.

(2) The thinness of the stratum of dielectric between them; and

(3) The dielectric capacity of the material.

59. The Leyden Jar. — The Leyden jar, called after the city where it was invented, is a convenient form of

condenser. It usually consists (Fig. 43) of a glass jar coated up to a certain height on the inside and outside with tinfoil. A brass knob fixed on the end of a stout brass wire passes downward through a lid or top of dry well-varnished wood, and communicates by a loose bit of brass chain with the inner coating of foil. To charge the jar the knob is held to the prime conductor of an electrical machine, the outer coating being either held in the hand or connected to "earth" by a wire or chain. When a + charge of electricity is imparted thus to the inner coating, it acts inductively on the outer coating, attracting a − charge into the face of the outer coating nearest the glass, and repelling a + charge to the outside of the outer coating, and thence through the hand or wire to earth. After a few moments the jar will have acquired its full charge, the outer coating being − and the inner +. If the jar is of good glass, and dry, and free from dust, it will retain its charge for many hours or days. But if a path be provided by which the two mutually attracting electricities can flow to one another, they will do so, and the jar will be instantaneously discharged. If the outer coating be grasped with one hand, and the knuckle of the other hand be presented to the knob of the jar, a bright spark will pass between the knob and the knuckle with a sharp report, and at the same moment a convulsive "shock" will be communicated to the muscles of the wrists, elbows, and shoulders. A safer means of discharging the jar is afforded by the **discharging tongs** or **discharger** (Fig. 44), which consists of a jointed brass rod provided with brass knobs and a glass handle. One knob is laid against the outer coating, the other is then

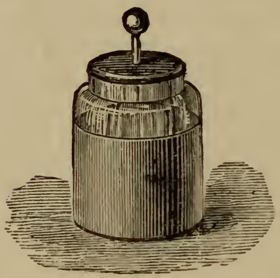

Fig. 43.

brought near the knob of the jar, and a bright snapping spark leaping from knob to knob announces that the two accumulated charges have flowed together, completing the discharge. Sometimes a jar discharges itself by a spark climbing over the top edge of the jar. Often when a jar is well charged a hissing sound is heard, due to partial discharges creeping over the edge. They can be seen in the dark as pale phosphorescent streams.

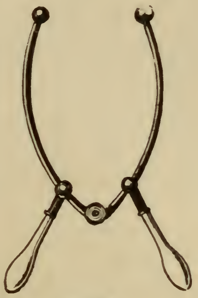

Fig. 44.

60. Discovery of the Leyden Jar. — The discovery of the Leyden jar arose from the attempt of Musschenbroek and his pupil Cuneus * to collect the supposed electric "fluid" in a bottle half filled with water, which was held in the hand and was provided with a nail to lead the "fluid" down through the cork to the water from the electric machine. Here the water served as an inner coating and the hand as an outer coating to the jar. Cuneus on touching the nail received a shock. This accidental discovery created the greatest excitement in Europe and America.

61. Residual Charges. — If a Leyden jar be charged and discharged and then left for a little time to itself, it will be found on again discharging that a small second spark can be obtained. There is in fact a **residual charge** which seems to have soaked into the glass or been absorbed. The return of the residual charge is hastened by tapping the jar. The amount of the residual charge varies with the time that the jar has been left charged; it also depends on the kind of the glass of which the jar is made. There is no residual charge discoverable in an air-leyden after it has once been discharged.

* The honour of the invention of the jar is also claimed for Kleist, Bishop of Pomerania.

62. Batteries of Leyden Jars. — A large Leyden jar will give a more powerful shock than a small one, for a larger charge can be put into it; its capacity is greater. A Leyden jar made of *thin* glass has a greater capacity as a condenser than a thick one of the same size; but if it is too thin it will be destroyed when powerfully charged

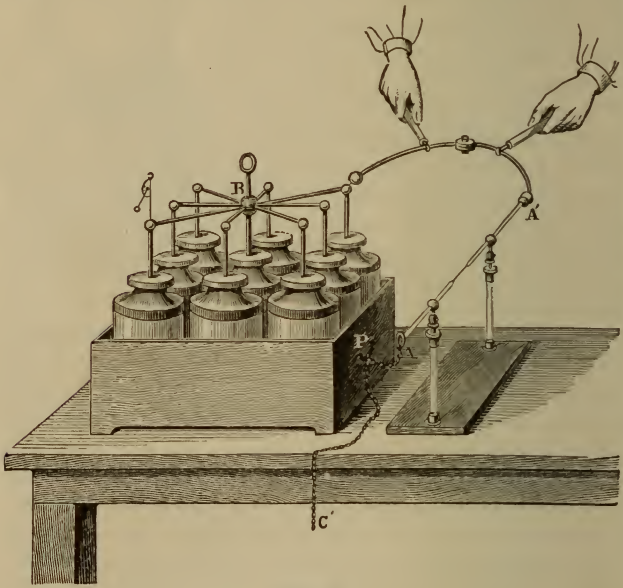

Fig. 45.

by a spark actually piercing the glass. "Toughened" glass is less easily pierced than ordinary glass, and hence Leyden jars made of it may be made thinner, and so will hold a greater charge. To prevent jars from being pierced by a spark, the highest part of the inside coating should be connected across by a strip of foil or a metallic disk to the central wire.

If a jar is desired to give *long sparks*, there must be

left a long space of varnished glass above the top of the coatings.

If it is desired to accumulate a very great charge of electricity, a number of jars must be employed, all their inner coatings being connected together, and all their outer coatings being united. This arrangement is called a **battery of Leyden jars**, or Leyden battery (Fig. 45). As it has a large capacity, it will require a large quantity of electricity to charge it fully. When charged it produces very powerful effects; its spark will pierce glass readily, and every care must be taken to avoid a shock from it passing through the person, as it might be fatal. The "Universal Discharger" as employed with the Leyden battery is shown at the right of the figure.

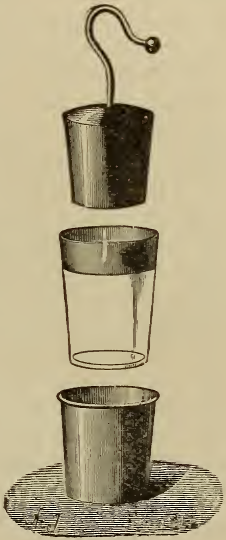

Fig. 46.

63. Seat of the Charge. — Benjamin Franklin discovered that the charges of the Leyden jar really reside on the surface of the glass, not on the metallic coatings. This he proved by means of a jar whose coatings could be removed (Fig. 46). The jar was charged and placed upon an insulating stand. The inner coating was then lifted out, and the glass jar was then taken out of the outer coating. Neither coating was found to be electrified to any extent, but on again putting the jar together it was found to be highly charged. The charges had all the time remained upon the inner and outer surfaces of the glass dielectric.

64. Dielectric Strain. — Farady proved that the medium across which influence takes place really plays an

important part in the phenomena. It is now known that all dielectrics across which inductive actions are at work are thereby *strained*.* Inasmuch as a good vacuum is a good dielectric, it is clear that it is not necessarily the material particles of the dielectric substance that are thus affected; hence it is believed that electrical phenomena are due to stresses and strains in the so-called "ether," the thin medium pervading all matter and all space, whose highly elastic constitution enables it to convey to us the vibrations of light though it is millions of times less dense than air. As the particles of bodies are intimately surrounded by ether, the strains of the ether are also communicated to the particles of bodies, and they too suffer a strain. The glass between the two coatings of tinfoil in the Leyden jar is actually strained or squeezed, there being a tension along the lines of electric force. When an insulated charged ball is hung up in a room an equal amount of the opposite kind of charge is attracted to the inside of the walls, and the air between the ball and the walls is strained (electrically) like the glass of the Leyden jar. If a Leyden jar is made of thin glass it may give way under the stress; and when a Leyden jar is discharged the layer of air between the knob of the jar and the knob of the discharging tongs is more and more strained as they are approached towards one another, till at last the stress becomes too great, and the layer of air gives way, and is "perforated" by the spark that discharges itself across. The existence of such stresses enables us to understand the residual charge of Leyden jars in which the glass does not recover itself all at once, by reason of its viscosity, from the strain to which it has been subjected. It must never be forgotten that electric force acts across space in consequence of the transmission of stresses and strains in the

* In the exact sciences a *strain* means an alteration of form or volume due to the application of a stress. A *stress* is the force, pressure, or other agency which produces a strain.

medium with which space is filled. In every case we store not electricity but *energy.* Work is done in pushing electricity from one place to another against the forces which tend to oppose the movement. The charging of a Leyden jar may be likened to the operation of bending a spring, or to pumping up water from a low level to a high one. In charging a jar we pump exactly as much electricity out of the negative side as we pump into the positive side, and we spend energy in so doing. It is this stored energy which afterwards reappears in the discharge.

Lesson VII. — *Other Sources of Electrification*

65. It was remarked at the close of Lesson I. (p. 13) that **friction** was by no means the only source of electricity. Some of the other sources will now be named.

66. Percussion. — A violent blow struck by one substance upon another produces opposite electrical states on the two surfaces. It is possible indeed to draw up a list resembling that of Art. 6, in such an order that each substance will take a + charge on being struck with one lower on the list.

67. Vibration. — Volpicelli showed that vibrations set up within a rod of metal coated with sulphur or other insulating substance, produced a separation of electricities at the surface separating the metal from the non-conductor.

68. Disruption and Cleavage. — If a card be torn asunder in the dark, sparks are seen, and the separated portions, when tested with an electroscope, will be found to be electrical. The linen faced with paper used in making strong envelopes and for paper collars, shows this very well. Lumps of sugar, crunched in the dark between the teeth, exhibit pale flashes of light. The

sudden cleavage of a sheet of mica also produces sparks, and both laminæ are found to be electrified.

69. Crystallization and Solidification. — Many substances, after passing from the liquid to the solid state, exhibit electrical conditions. Sulphur fused in a glass dish and allowed to cool is violently electrified, as may be seen by lifting out the crystalline mass with a glass rod. Chocolate also becomes electrical during solidification. When arsenic acid crystallizes out from its solution in hydrochloric acid, the formation of each crystal is accompanied by a flash of light, doubtless due to an electrical discharge. A curious case occurs when the sulphate of copper and potassium is fused in a crucible. It solidifies without becoming electrical, but on cooling a little further the crystalline mass begins to fly to powder with an instant evolution of electricity.

70. Combustion. — Volta showed that combustion generated electricity. A piece of burning charcoal, or a burning pastille, such as is used for fumigation, placed in connexion with the knob of a gold-leaf electroscope, will cause the leaves to diverge.

71. Evaporation. — The evaporation of liquids is often accompanied by electrification, the liquid and the vapour assuming opposite states, though apparently only when the surface is in agitation. A few drops of a solution of sulphate of copper thrown into a hot platinum crucible produce violent electrification as they evaporate.

72. Atmospheric Electricity. — The atmosphere is found to be always electrified relatively to the earth: this is due, in part possibly, to evaporation going on over the oceans. The subject of atmospheric electricity is treated of separately in Lesson XXV.

73. Pressure. — A large number of substances when compressed exhibit electrification on their surface. Thus cork becomes + when pressed against amber, gutta-percha, and metals; while it takes a – charge when

pressed against spars and animal substances. Péclet found the degree of electrification produced by rubbing two substances together to be independent of the pressure and of the size of the surfaces of contact, but depended upon the materials and on the velocity with which they moved over one another. Rolling contact and sliding friction produced equal effects.

74. **Pyro-electricity.** — There are certain crystals which, while being heated or cooled, exhibit electrical charges at certain regions or poles. Crystals thus electrified by heating or cooling are said to be **pyro-electric.** Chief of these is the **Tourmaline**, whose power of attracting light bodies to its ends after being heated has been known for some centuries. It is alluded to by Theophrastus and Pliny under the name of *Lapis Lyncurius.* Tourmaline is a hard mineral, semi-transparent when cut into thin slices, and of a dark green or brown colour, but looking perfectly black and opaque in its natural condition, and possessing the power of polarizing light. It is usually found in slightly irregular three-sided prisms which, when perfect, are pointed at both ends. It belongs to the "hexagonal" system of crystals, but is only hemihedral, that is to say, has the alternate faces only developed. Its form is given in Fig. 47, where a general view is first shown, the two ends A and B being depicted in separate plans. These two ends differ slightly in shape. Each is made up of three sloping faces terminating in a point. But at A the edges between these faces run down to the corners of the prism, while in B the edges between the terminal faces run down to the middle points of the long faces of the prism. The end A is known as the **analogous** pole, and B as the **antilogous** pole. While the crystal is rising in temperature A exhibits + electrification, B – ; but if, after having been heated, it is allowed to cool, the polarity is reversed; for during the time that the temperature is falling B is + and A is –. If the temperature is

steady no such electrical effects are observed either at high or low temperatures; and the phenomena cease if the crystal be warmed above 150° C. This is not, however, due to the crystal becoming a conductor at that temperature; for its resistance at even higher temperatures is still so great as to make it practically a non-conductor. A heated crystal of tourmaline suspended by a silk fibre may be attracted and repelled by electrified bodies, or by a second heated tourmaline; the two similar poles repelling one another, while the two poles

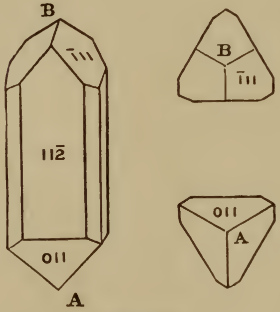

Fig. 47.

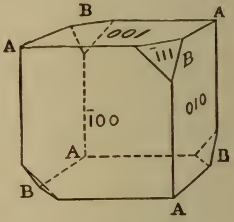

Fig. 48.

of opposite form attract one another. If a crystal be broken up, each fragment is found to possess also an analogous and an antilogous pole.

Many other crystals beside the tourmaline are more or less pyro-electric. Amongst these are silicate of zinc ("electric calamine"), boracite, cane-sugar, quartz, tartrate of potash, sulphate of quinine, and several others. *Boracite* crystallizes in the form shown in Fig. 48, which represents a cube having four alternate corners truncated. The corners not truncated behave as analogous poles, the truncated ones as antilogous. When a natural hexagonal prism of quartz is heated its six edges are found to be + and − in alternate order.

75. Piezo-electricity.—In certain crystals pressure in a particular direction may produce electrification. Haüy found that a crystal of calcspar pressed between the dry fingers, so as to compress it along the blunt edges of the crystal, became electrical, and that it retained its electricity for some days. He even proposed to employ a squeezed suspended crystal as an electroscope. A similar property is alleged of mica, topaz, and fluorspar. If two opposite edges of a hexagonal prism of quartz are pressed together, one becomes +, the other −. Pressure also produces opposite kinds of electrification at opposite ends of a crystal of tourmaline, and of other crystals of the class already noticed as possessing the peculiarity of skew-symmetry or hemihedry in their structure. *Piezo-electricity* is the name given to this branch of the science. It is known that skew-symmetry of structure is dependent on molecular constitution; and it is doubtless the same peculiarity which determines the pyro-electric and piezo-electric properties, as well as the optical behaviour of these crystals in polarized light.

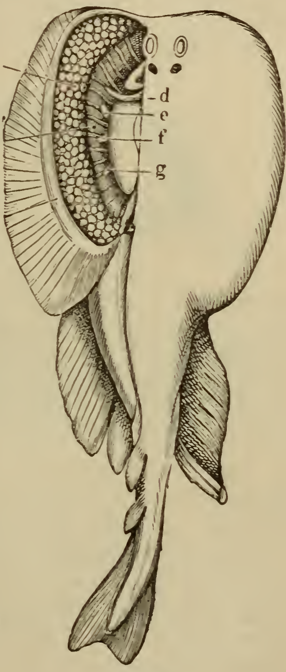

Fig. 49.

76. Animal Electricity.—Several species of creatures inhabiting the water have the power of producing electric discharges physiologically. The best known of these creatures are the *Torpedo*, the *Gymnotus*, and the

Silurus. The **Raia Torpedo**,* or electric ray, of which there are three species inhabiting the Mediterranean and Atlantic, is provided with an electric organ on the back of its head, as shown in Fig. 49. This organ consists of laminæ composed of polygonal cells to the number of 800 or 1000, or more, supplied with four large bundles of nerve fibres; the under surface of the fish is −, the upper +. In the **Gymnotus electricus**, or Surinam eel (Fig. 50), the electric organ goes the whole length of the body from tail to head. Humboldt gives a lively account of the

Fig. 50.

combats between the electric eels and the wild horses, driven by the natives into the swamps inhabited by the Gymnotus. It is able to give a most terrible shock, and is a formidable antagonist when it has attained its full length of 5 or 6 feet. In the **Silurus** the current flows from head to tail.

Nobili, Matteucci, and others, have shown that nerve-excitations and muscular contractions of human beings also give rise to feeble discharges of electricity.

77. **Electricity of Vegetables.**—Buff thought he detected electrification produced by plant life; the roots and juicy parts being negatively, and the leaves positively, electrified. The subject has, however, been little investigated.

* It is a curious point that the Arabian name for the torpedo, *ra-ad*, signifies *lightning*. This is perhaps not so curious as that the *Electra* of the Homeric legends should possess certain qualities that would tend to suggest that she is a personification of the *lightning*. The resemblance between the names *electra* and *electron* (amber) cannot be accidental.

78. Thermo-electricity. — *Heat* applied at the junction of two dissimilar metals produces a flow of electricity across the junction. This subject is discussed in Lesson XXXV. on *Thermo-electric Currents*.

79. Contact of Dissimilar Metals. — Volta showed that the contact of two dissimilar metals in air produced opposite kinds of electrification, one becoming positively, and the other negatively, electrified. This he proved in several ways, one of the most conclusive proofs being that afforded by his *condensing electroscope*. This consisted of a gold-leaf electroscope combined with a small condenser. A metallic plate formed the top of the electroscope, and on this was placed a second metallic plate furnished with a handle, and insulated from the lower one by being well varnished at the surface (Fig. 51). As the capacity of such a condenser is considerable, a very feeble source may supply a quantity of electricity to the condenser without materially raising its potential, or causing the gold leaves to diverge. But if the upper plate be lifted, the capacity of the lower plate diminishes enormously, and the potential of its charge rises as shown by the divergence of the gold leaves.* To prove by the con-

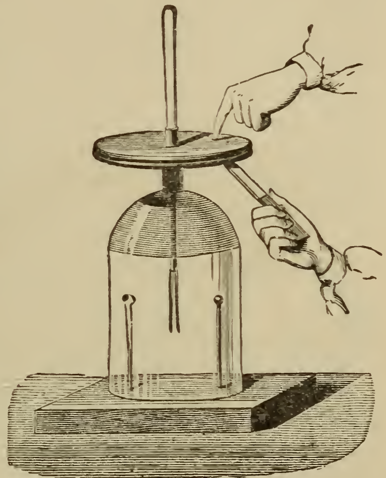

Fig. 51.

* Formerly, this action was accounted for by saying that the electricity which was "bound" when the plates of the condenser were close together,

densing electroscope that contact of dissimilar metals does produce electrification, a small compound bar made of two dissimilar metals — say zinc and copper — soldered together, is held in the moist hand, and one end of it is touched against the lower plate, the upper plate being placed in contact with the ground or touched with the finger. When the two opposing charges have thus collected in the condenser the upper plate is removed, and the diverging of the gold leaves shows the presence of a free charge, which can afterwards be examined to see whether it be + or −. Instead of employing the copper-zinc bar, a single voltaic cell may be connected by copper wires to the two plates. For a long time the existence of this electrification by contact was denied, or rather it was declared to be due (when occurring in voltaic combinations such as are described in Lesson XIII.) to chemical actions going on; whereas the real truth is that the electricity of contact and the chemical action are both due to molecular conditions of the substances which come into contact with one another, though we do not yet know the precise nature of the molecular conditions which give rise to these two effects. Later experiments, especially those made with the modern delicate electrometers of Lord Kelvin, put beyond doubt the reality of Volta's discovery. One simple experiment explains the method adopted. A thin strip or needle of metal is suspended so as to turn about a point *C*. It is electrified from a known source. Under it are placed (Fig. 52) two semicircular disks, or half-rings of dissimilar

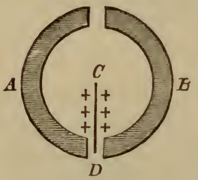

Fig. 52.

becomes "free" when the top plate is lifted up; the above is, however, a more scientific and more accurate way of saying the same thing. The student who is unable to reconcile these two ways of stating the matter should read again Articles 40 and 55, on pp. 46 and 68. A much more sensitive apparatus to show the effect is the quadrant electrometer (Art. 288).

metals. Neither attracts or repels the electrified needle until the two are brought into contact, or connected by a third piece of metal, when the needle immediately turns, being attracted by the one that is oppositely electrified, and repelled by the one that is electrified similarly with itself.

80. Contact Series of Metals (in Air). — Volta found, moreover, that the differences of electric potential between the different pairs of metals were not all equal. Thus, while zinc and lead were respectively + and − to a slight degree, he found zinc and silver to be respectively + and − to a much greater degree. He was able to arrange the metals in a series such that each one enumerated became positively electrified when placed in contact in air with one below it in the series. Those in italics are added from observations made since Volta's time —

+ *Sodium*,	Copper,
Magnesium,	Silver,
Zinc,	Gold,
Lead,	*Platinum*,
Tin,	− *Graphite* (Carbon).
Iron,	

Though Volta gave rough approximations, the actual numerical values of the differences of potential in air for different pairs of metals have only lately been measured by Ayrton and Perry, a few of whose results are tabulated here —

	Difference of Potential (volts).
Zinc — Lead	·210
Lead — Tin	·069
Tin — Iron	·313
Iron — Copper	·146
Copper — Platinum	·238
Platinum — Carbon	·113

The difference of potential between zinc and carbon is the same as that obtained by adding the successive differences, or 1·09 volts.* Volta's observations may therefore be stated in the following generalized form, known as **Volta's Law.** *The difference of potential between any two metals is equal to the sum of the differences of potentials between the intervening metals in the contact-series.*

It is most important to notice that the order of the metals in the contact-series *in air* is almost identical with that of the metals arranged according to their electro-chemical power, as calculated from their chemical equivalents and their heat of combination with oxygen (see Table, Art. 489). From this it would appear that the difference of potentials between a metal and the air that surrounds it measures the tendency of that metal to become oxidized by the air. If this is so, and if (as is the case) the air is a bad conductor while the metals are good conductors, it ought to follow that when two different metals touch they equalize their own potentials by conduction but leave the films of air that surround them at different potentials. All the exact experiments yet made have measured the difference of potentials not between the metals themselves, but between the air near one metal and that near another metal. It is certain that while in air iron is positive to copper, but in an atmosphere of sulphuretted hydrogen, iron is negative to copper. Mr. John Brown has lately demonstrated the existence on freshly-cleaned metal surfaces of *films* of liquid or condensed gases, and has shown that polished zinc and copper, when brought so near that their films touch, will act as a battery.

81. Contact Actions. — A difference of potential is also produced by the contact of *two dissimilar liquids* with one another.

* For the definition of the *volt*, or unit of difference of potential, see Art. 254.

A *liquid and a metal* in contact with one another also exhibit a difference of potential, and if the metal tends to dissolve into the liquid chemically there will be an electromotive force acting from the metal toward the liquid.

The thermo-electric difference of potential at a junction of two metals is a true contact difference. It is measured by the amount of heat produced (see *Peltier-effect*, Art. 420) by passing a current of electricity in the reverse direction through the junction.

A *hot* metal placed in contact with a *cold* piece of the same metal also produces a difference of potential, electrical separation taking place across the surface of contact.

Lastly, it has been shown by Professor J. J. Thomson that the surface of contact between two non-conducting substances, such as sealing-wax and glass, is the seat of a permanent difference of potentials.

82. Magneto-electricity. — Electric currents flowing along in wires can be obtained from magnets by moving closed conducting circuits in their neighbourhood. This source is dealt with in Art. 222, Lesson XVIII.

83. Summary. — We have seen in the preceding paragraphs how almost all conceivable agencies may produce electrification in bodies. The most important of these are friction, heat, chemical action, magnetism, and the contact of dissimilar substances. We noted that the production of electricity by friction depended largely upon the molecular condition of the surfaces. We may here add that the difference of potentials produced by contact of dissimilar substances also varies with the temperature and with the nature of the medium (air, vacuum, etc.) in which the experiments are made. Doubtless this source also depends upon the molecular conditions of dissimilar substances being different; the particles at the surfaces being of different sizes and shapes, and vibrating with different velocities and with

different forces. There are (see Art. 10) good reasons for thinking that the electricity of friction is really due to electricity of contact, excited at successive portions of the surfaces as they are moved over one another. But of the molecular conditions of bodies which determine the production of electrification where they come into contact, little or nothing is yet known.